

N-80K

PROGRAM & REPORT

Prepared for the

Space Mechanics Division of the

LANGLEY RESEARCH CENTER

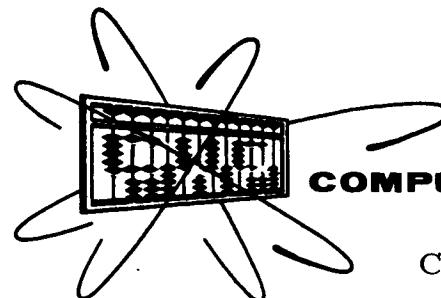
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PART 4
INTEGRATION PROGRAM

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SECTION I
INTRODUCTION

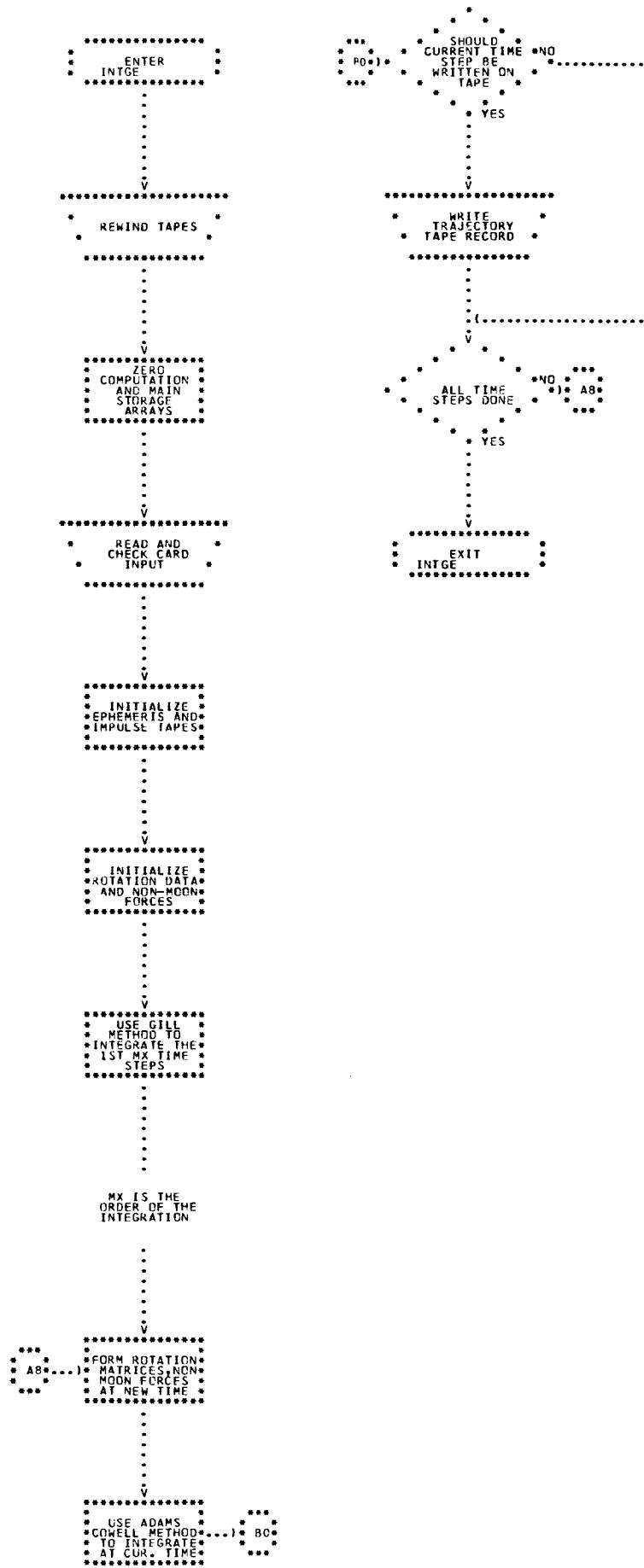
INTRODUCTION

From given initial coordinates and velocities, or from given initial orbital elements, the equations of motion and perturbation equations are numerically integrated by INTGE with a fixed time-step size. The method used is a twelfth order predictor-corrector procedure in Lagrangian form, with Gill's version of the Runge-Kutta method used to provide starting values. In addition to perturbations in the initial position and velocity or orbital elements, perturbations may be integrated for up to 58 harmonics of the Moon's gravitational field, for 3 radiation pressure parameters, each applying over a particular period of time, and for 2 control thrust forces, the latter assumed to occur at a known time but to be of unknown magnitude.

SECTION II
SYSTEM FLOW CHART

INTEGRATION SYSTEM FLOW CHART

1



SECTION III
USER INFORMATION

INPUT CARDS

1) Card type 10; Format (I5, 2X, I8, 2X, 3A6, 2X, 3A6, I5)

<u>MN</u>	<u>FORMAT</u>	<u>CARD COL</u>	<u>DEFINITION</u>
IT	I5	1-5	Card type, "10"
ID	I8	8-15	Run identification number
RUNAME	3A6	18-35	Run name, for user information only
RNDATE	3A6	38-55	Run date, for user information only
IYRDYS	I5	56-60	Number of days in the start year

2) Card type 20, Format (I5, 20L1)

The following are the program options: A T (TRUE) sets the option on, a F (FALSE) or a blank sets it off.

IT	I5	1-5	Card type, "20"
CORE	L1	6	Correct predicted values
PERTS	L1	7	Calculate perturbations
ARCIT	L1	8	Arc iteration
PRNT	L1	9	Print trajectory or perturbations (on PRNTRJ or PRNTP)
PRNTRJ	L1	10	Print trajectory
PRNTP	L1	11	Print perturbations
PRNTIN	L1	12	Print input gravity arrays
PRNLOG	L1	13	Print elements of LOGIC common
PRFOR	L1	14	Prints some U and DU arrays on initial time step
PRSTRT	L1	15	Prints entire coordinate force, pertur- bation and perturbation force arrays from the starting procedure

<u>MN</u>	<u>FORMAT</u>	<u>CARD COL</u>	<u>DEFINITION</u>
PEPHEM	L1	16	Print ephemeris data for each day of run
ORBIN	L1	20	Orbital elements are input to the program
ORBUSE	L1	21	Perturbations for orbital elements are calculated
VTAPE	L1	22	A tape of impulses from orbit corrections is mounted
TPERT	L1	25	Dumps all arrays for each perturbation at each time step in the main procedure

3) Card type 30, Format (I5, 2D25.16)

IT	I5	1-5	Card type, "30"
GRAVMN	D25.16	6-30	Moon gravity
RMOON	D25.16	31-55	Moon radius in KM

4) Card type 31, Format (I5, 2D25.16)

IT	I5	1-5	Card type, "31"
GRAVEH	D25.16	6-30	Earth gravity
GRAVSN	D25.16	31-55	Sun gravity

5) Card type 40, Format (I5, 2X, I8, D15.8, 2X, 3A6)

IT	I5	1-5	Card type, "40"
ISATNO	I8	8-15	Satellite number
SMASS	D15.8	16-30	Satellite mass
SNAME	3A6	33-50	Satellite name, for edit purposes only

6) Card type 200, Format (8I5)

<u>MN</u>	<u>FORMAT</u>	<u>CARD COL</u>	<u>DEFINITION</u>
IT	I5	1-5	Card type, "200"
MMAX	I5	6-10	Maximum M in gravity coefficients C_N^M
NMAX(I)	6I5	11-40	Maximum N in gravity coefficients C_N^{I-1} , I=1,6

7) Card type 210, Format (3I5, 2D25.16)

IT	I5	1-5	Card type, "210"
M N	I5 I5	6-10 11-15	Identifiers for gravity pair C_N^M and S_N^M
C	D25.16	16-40	Value for C_N^M
S	D25.16	41-65	Value for S_N^M

These cards are necessary only for non-zero values of C_N^M and S_N^M . The M and N given must conform to the constraints set up by MMAX and NMAX(I).

8) Card type 299, Format (3I5, 2D25.16)

IT	I5	1-5	Card type, "299"
----	----	-----	------------------

This is the end card for the gravity parameters. All fields except the first should be blank.

9) Card type 300, Format (5I5, I10, 2I5, D25.16)

IT	I5	1-5	Card type, "300"
MX	I5	6-10	Order of integration
INTTS	I5	11-15	Time step for integration, in seconds
IGPC	I5	16-20	Number of starting procedure time steps per Cowell time step

<u>MN</u>	<u>FORMAT</u>	<u>CARD COL</u>	<u>DEFINITION</u>
IMU	I5	21-25	Number of Cowell time steps per tape store
NUMSTP	I10	26-35	Number of time steps to be stored on tape
ISYR	I5	36-40	Start year for integration
ISDAY	I5	41-45	Start day for integration
TZDAY	D25.16	46-70	Start time in seconds from beginning of ISDAY

10) Card type 310 through 323, Format (I5, 2D25.16)

These are the coefficients for the Adams-Cowell formulae. There are MX+2 cards, where the MX+2 card has the LCD.

IT	I5	1-5	Card type, 310, 311, . . . , to maximum of 323.
GAMMA(I)	D25.16	6-30	Gamma coefficients, I=1, MX+2
ALPHA(I)	D25.16	31-55	Alpha coefficients, I=1, MX=2

11) Card type 400, Format (I5, 2D25.16)

IT	I5	1-5	Card type, "400"
XZERO(1)	D25.16	6-30	Initial position, X direction in KM/SEC; or Orbital Element a
XDOTO(1)	D25.16	31-55	Initial velocity, X direction in KM/SEC; or Orbital Element i

12) Card type 410, Format (I5, 2D25.16)

IT	I5	1-5	Card type, "410"
XZERO(2)	D25.16	6-30	Initial position, Y direction in KM/SEC; or Orbital Element e _s
XDOTO(2)	D25.16	31-55	Initial velocity, Y direction, in KM/SEC; or Orbital Element m _o

13) Card type 420, Format (I5, 2D25.16)

<u>MN</u>	<u>FORMAT</u>	<u>CARD COL</u>	<u>DEFINITION</u>
IT	I5	1-5	Card type, "420"
XZERO(3)	D25.16	6-30	Initial position, Z direction in KM/SEC; Orbital Element e_c .
XDOTO(3)	D25.16	31-55	Initial velocity, Z direction in KM/SEC; Orbital Element Ω .

14) Card type 500, Format (2I5)

IT	I5	1-5	Card type, "500"
NUMRAD	I5	6-10	Number of Radiation Pressure para- meters, maximum of three

15) Card type 510, 520 and 530, Format (I5, 2D25.16)

IT	I5	1-5	Card type, 510, 520 or 530
RTIME(K)	D25.16	6-30	End day of run for use of K-th para- meter
RPARAM(K)	D25.16	31-55	K-th Radiation pressure parameter, where $K \leq 3$. $RPARAM(K) = \frac{R_K}{10^8}$

$K=1$ to NUMRAD. The actual radiation pressure value, R_K , must be divided by 10^8 , and the result is used as RPARAM(K).

16) Card type 600, Format (2I5)

IT	I5	1-5	Card type, "600"
NUMTHR	I5	6-10	Number of thrust parameter sets, one or two.

17) Card type 610 and 620, Format (I5, 3D15.8, D20.13)

<u>MN</u> <u>IT</u>	<u>FORMAT</u> <u>I5</u>	<u>CARD COL</u> <u>1-5</u>	<u>DEFINITION</u> Card type, "610 or "620" in KM/SEC
TX(1,K)	D15.8	6-20	Thrust in X direction in KM/SEC
TX(2,K)	D15.8	21-35	Thrust in Y direction in KM/SEC
TX(3,K)	D15.8	36-50	Thrust in Z direction in KM/SEC
TTIME(K)	D20.13	51-70	Time of thrust in seconds from the start of the year

K=1, NUMTHR

NOTE These input cards must be in sort by card type

OPERATING INSTRUCTIONS

- 1) The system control cards required in the overall deck setup are:

\$JOB

\$SETUP 04

\$SETUP 05

\$SETUP 14 (omit if impulse tape option off)

\$EXECUTE IBJOB

\$IBJOB INTGE decks, source or binary

\$DATA

INTGE data cards

- 2) The tape setup is:

<u>DCS Unit</u>	<u>Tape Function</u>
04	Output Trajectory tape
05	Input Ephemeris tape
14	Input Impulse tape
15	Scratch tape or disk file

- 3) The output consists of the trajectory tape on unit 04 and printing.

PROGRAM RESTRICTIONS

1. In defining the gravity coefficients C_N^M , S_N^M the following restrictions on M and N are imposed:
 - a) $M \leq 10$
 - b) $M+N \leq 10$, and $N \geq M$
2. The order of the integration cannot exceed twelve.
3. The number of radiation pressure parameters cannot exceed three.
4. The number of thrust parameters cannot exceed two.
5. Any impulse forces from tape which occur during the starting procedure integration will not be processed.

ERROR LIST

<u>NUMBER</u>	<u>ROUTINE</u>	<u>MEANING</u>
	<u>INPUT</u>	
10		Card type 10 is missing or out of sort
20	INPUT	Card type 20 is missing or out of sort
30	INPUT	Card type 30 is missing or out of sort
31	INPUT	Card type 31 is missing or out of sort
40	INPUT	Card type 40 is missing or out of sort
201	GIN	Card type 200 is missing or out of sort
202	GIN	MMAX less than zero
203	GIN	NMAX(1) greater than ten
204	GIN	Row of gravity array defined longer than dimensioned.
205	GIN	Row I longer than raw I-1
206	GIN	Card 210 out of sort
207	GIN	Gravity coefficient M greater than defined MMAX
208	GIN	Gravity coefficient N greater than defined NMAX(M+1)
300	INPUT	Card type 300 is missing or out of sort
310-323	INPUT	One of the Adams-Cowell coefficient cards is missing
324	INPUT	MX is greater than 12, so too many Adams-Cowell coefficient cards were read

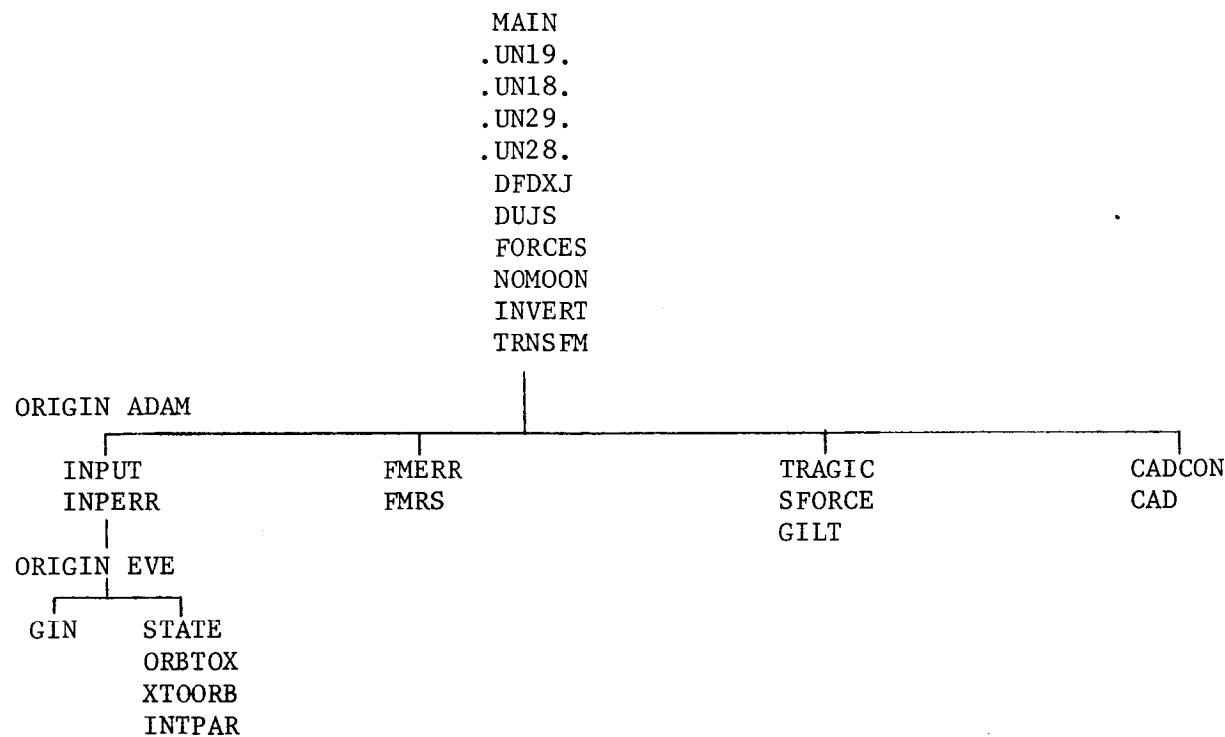
<u>NUMBER</u>	<u>ROUTINE</u>	<u>MEANING</u>
	INPUT	
400	INPUT	Card type 400 is missing or out of sort
410	INPUT	Card type 410 is missing or out of sort
420	INPUT	Card type 420 is missing or out of sort
500	INPUT	Card type 500 is missing or out of sort
510	INPUT	Card type 510 is missing or out of sort
520	INPUT	Card type 520 is missing or out of sort
530	INPUT	Card type 530 is missing or out of sort
600	INPUT	Card type 600 is missing or out of sort
610	INPUT	Card type 610 is missing or out of sort
620	INPUT	Card type 620 is missing or out of sort

The following error numbers are printed with the message "RUN WAS STOPPED BECAUSE OF EPHemeris TAPE ERROR XXX"

1400	FMRS	No type record on ephemeris tape
1401	FMRS	Year of ephemeris tape is not equal to start year of run
1402	FMRS	Ephemeris data doesn't span the run, or the last days of run not on tape.
1410	FMRS	Record type 410 missing from ephemeris tape
1411	FMRS	Ephemeris time and program time don't match
1700	FMRS	Impulse tape header record type is not 100
1701	FMRS	The satellite numbers of impulse tape and run don't match
1702	FMRS	Impulse tape data record type is not 110

<u>NUMBER</u>	<u>ROUTINE</u>	<u>MEANING</u>
1700	FMRS	Impulse tape header record type is not 100
1701	FMRS	The satellite numbers of impulse tape and run don't match
1702	FMRS	Impulse tape data record type is not 110.

PROGRAM DECK ARRANGEMENT



FILE BLOCK PROGRAM OPTIONS

- 1) Tape 18:
 Filename is "UNIT18"
 Mode is "BIN"
 Unit assignment is "A(1)"
- 2) Tape 19:
 Filename is "UNIT19"
 Mode is "BIN"
 Unit assignment is "A(2)"
- 3) Tape 28
 Filename is "UNIT28"
 Mode is "BIN"
 Unit assignment is "B(1)"
- 4) Tape 29
 Filename is "UNIT29"
 Mode is "BIN"
 Unit assignment is "B(2)"

IMPULSE TAPE

RECORD TYPES	100	Tape header record
	110	Impulse data record
	120	Tape trailer record

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENT
100	1	IT	INTEGER	Record type, "100"
	1	NOSAT	INTEGER	Satellite number
110	1	IT	INTEGER	Record type, "110"
	1x2	VTIME	DOUBLE	Time of impulse
	3x2	V	DOUBLE	Impulse forces in X,Y and Z direction
120	1	IT	INTEGER	Record type, "120"
	8	IDUM	INTEGER	Padding to fill record out to length of 110 record

SYSTEM EPHEMERIS TAPE

RECORD TYPES

400	Ephemeris Tape Header
410	Repeated Data Records
420	Ephemeris End of File Record

RECORD TYPE	# OF WORDS	MN	FORMAT	CONTENTS
400	1	IRCTP1	INTEGER	Record type
	1	IYEAR	INTEGER	Year of this ephemeris tape
	1	IDAY1	INTEGER	First day of this ephemeris tape
	1	ISPAN	INTEGER	Number of records (days) on ephemeris tape
	1x2	YRSECS	DOUBLE	Number of seconds in this year
	1x2	H1	DOUBLE	Mean hour angle of Greenwich meridian at Jan 0.0 o current year
	1x2	H2	DOUBLE	Mean hour angle of Greenwich meridian at Jan 0.0 of next year
410	1	IRCTP2	INTEGER	Record type
	1	IDAY	INTEGER	Day of this record
	(3x9)x2	PXE	DOUBLE	Polynomial coefficients for earth's coordinates
	(3x5)x2	PXS	DOUBLE	Polynomial coefficients for sun's coordinates
	(3x3x5)x2	PCDTR	DOUBLE	Polynomial coefficients for $(CD)^T$ matrix
	(3x3x5)x2	PECCTR	DOUBLE	Polynomial coefficients for $(ECD)^T$ matrix
	1x2	TZERO	DOUBLE	Midpoint of this day in seconds from start of year
	5x2	PDELH	DOUBLE	Polynomial coefficients for ΔH

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENTS
420	1	IRCTP3	INTEGER	Record type
	1	IDAY	INTEGER	Day of last record
	(3x9)x2	PXE	DOUBLE	Repeat of last record
	(3x5)x2	PXS	DOUBLE	Repeat of last record
	(3x3x5)x2	PCDTR	DOUBLE	Repeat of last record
	(3x3x5)x2	PECCTR	DOUBLE	Repeat of last record
	1x2	TZERO	DOUBLE	Repeat of last record
	5x2	PDELH	DOUBLE	Repeat of last record

TRAJECTORY AND PERTURBATION TAPE

RECORD TYPES

100	Trajectory tape header
110	Parameter and label record
120	Ephemeris header
130	Ephemeris records
140	Trajectory and perturbation records
150	Trajectory end of file record

FORMAT

RECORD TYPE	# OF WORDS	MN	FORMAT	CONTENT
100	1	ITYPET	INTEGER	Record type
	1	IDENTT	INTEGER	Identification number for arc
	1	ISATNO	INTEGER	Satellite number
	1	NUMGA	INTEGER	Number of partials calculated by INTEGRATION
	1	NUMGRV	INTEGER	Number of gravity partials calculated by INTEGRATION
	1	ISYR	INTEGER	Start year of ARC
	2	ARCSEC	DOUBLE	Start time of arc (seconds from beginning of year)
	2	ARCEND	DOUBLE	Time of last record (seconds from beginning of current year)
	2	DURA	DOUBLE	Duration of arc
	2	DELTAT	DOUBLE	Interval of storage

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENT
110	1	ITYPET	INTEGER	Record type
	NUMGAX2	PARAMS	DOUBLE	Initial parameter values for variables in integra- tion
	NUMGA	LABELS	INTEGER	Labels for parameters used in integration
120	1	ITYPET	INTEGER	Record type
	1	IDAY1	INTEGER	First day on tape (days from year start)
	1	IDAYS	INTEGER	Number of days of data equal number of Ephemeris records
	2	YRSECS	DOUBLE	Number of seconds in start year
	2	H1	DOUBLE	H for start year
130	2	H2	DOUBLE	H for second year
	1	ITYPET	INTEGER	Record type
	2	TZERO	DOUBLE	Base time for interpolation
	3x9x2	PXE	DOUBLE	INTERPOLATION Polynominal coefficients for earth- moon vector PXE(I,J)=I,3 J=1,9
	3x5x2	PCDTR	DOUBLE	Interpolation polynominal coefficients for Δh PBTR(I) I=1,5
	3x3x5x2	PECDTR	DOUBLE	PECDTR (I,II,J) I=1,3 II=1,3 J=1,5

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENT
140	1	ITYPET	INTEGER	Record type
	2	TIMET	DOUBLE	Time of (position, acceleration and perturbations) seconds from beginning of year
	3x2	XSAT	DOUBLE	Position of satellite at TIMET (KM)
	3x2	ASAT	DOUBLE	Acceleration of satellite at TIMET(KM)
	3xNUMGAx2	P	DOUBLE	Array of perturbations
150	1	ITYPET	INTEGER	Record type
	2	TIMET	DOUBLE	Time of last trajectory and perturbation set
	3x2	XSAT	DOUBLE	Last position
	3x2	ASAT	DOUBLE	Last acceleration
	3xNUMGAx2	P	DOUBLE	Last array of perturbations

ADAM COMMON DEFINITIONS

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
XSAT	(3x3)x2	DOUBLE	Satellite position
AIN	(3x3)x2	DOUBLE	Inverse of (I-Gamma xDFDX)
P	(2x3x75)x2	DOUBLE	Perturbation array
PHI	(13x3x75)x2	DOUBLE	Full perturbation forces
PS	3x2	DOUBLE	Temporary for perturbations

FARCE COMMON DEFINITIONS

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
UM2	11x2	DOUBLE	Row of U or V array
VM2	11x2	DOUBLE	Row of U or V array
UM1	12x2	DOUBLE	Row of U or V array
VM1	12x2	DOUBLE	Row of U or V array
UZERO	13x2	DOUBLE	Row of U or V array
VZERO	13x2	DOUBLE	Row of U or V array
U1	12x2	DOUBLE	Row of U or V array
V1	12x2	DOUBLE	Row of U or V array
U2	11x2	DOUBLE	Row of U or V array
V2	11x2	DOUBLE	Row of U or V array
U3	9x2	DOUBLE	Row of U or V array
V3	9x2	DOUBLE	Row of U or V array
U4	7x2	DOUBLE	Row of U or V array
V4	7x2	DOUBLE	Row of U or V array
U5	5x2	DOUBLE	Row of U or V array
V5	5x2	DOUBLE	Row of U or V array
U6	3x2	DOUBLE	Row of U or V array
V6	3x2	DOUBLE	Row of U or V array
U7	1x2	DOUBLE	Row of U or V array
V7	1x2	DOUBLE	Row of U or V array
PERTBF	12x2	DOUBLE	Buffer array so that PERT(3,75) can be equivalenced to UM2

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
DUM1	(11x3x2)x2	DOUBLE	Row of DUDX array
DU0	(12x3x2)x2	DOUBLE	Row of DUDX array
DU1	(11x3x2)x2	DOUBLE	Row of DUDX array
DU2	(9x3x2)x2	DOUBLE	Row of DUDX array
DU3	(7x3x2)x2	DOUBLE	Row of DUDX array
DU4	(5x3x2)x2	DOUBLE	Row of DUDX array
DU5	(3x3x2)x2	DOUBLE	Row of DUDX array
DU6	(1x3x2)x2	DOUBLE	Row of DUDX array
F	3x2	DOUBLE	Temporary force array
EXTRAF	3x2	DOUBLE	Non-Moon forces
FORCE	(13x3)x2	DOUBLE	Array of forces
PF	(3x75)x2	DOUBLE	Forces for perturbations DF/DPK
EXDFDX	(3x3)x2	DOUBLE	Non-Moon DFDX
DFDX	(3x3)x2	DOUBLE	Jacobian of forces WRT position
RSAT	1x2	DOUBLE	Satellite vector magnitude
FX	3x2	DOUBLE	Satellite vector in moon coordinates
ROTATE	(3x3)x2	DOUBLE	Rotation matrix
EPOS	3x2	DOUBLE	Earth position
SUNPOS	3x2	DOUBLE	Sun position
A	13x2	DOUBLE	Multipliers for DUDX
FACT1	12x2	DOUBLE	Multiplier for UM1
FACT2	11x2	DOUBLE	Multiplier for UM2

IMP COMMON DEFINITIONS

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
V	3x2	DOUBLE	Impulse vector from tape
VTIME	1x2	DOUBLE	Time of current impulse
DX	(3x2)x2	DOUBLE	Impulse forces
VTAPE	1	LOGICAL	Indicates whether an Impulse tape is mounted
VSTEP	1	LOGICAL	Indicates whether an Impulse occurs during current time step
IVFLAG	1	INTEGER	Pointer for Impulse force
ISATNO	1	INTEGER	Satellite number

LOGI COMMON DEFINITIONS

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
IGLPAC	1	INTEGER	Number of Gill timesteps per A-C time steps
INMULT	1	INTEGER	Number of A-C time steps per tape
NUMSTP	1	INTEGER	Number of tape time steps for the run
NSPTS	1	INTEGER	Number time steps in starting procedure
ISYR	1	INTEGER	Start year of run
ISDAY	1	INTEGER	Start day of run
IDAYS	1	INTEGER	Number of records of Ephemeris data on trajectory tape
NUMGRV	1	INTEGER	Number of gravity parameters
NUMRAD	1	INTEGER	Number of radiation parameters
NUMTHR	1	INTEGER	Number of thrust parameters
NUMGA	1	INTEGER	Number of parameters integrated (total)
IADD	1	INTEGER	Number of S gravity parameters
MX	1	INTEGER	Order of integration
MXP1	1	INTEGER	MX+1
MP	1	INTEGER	Order of integration for perturbations
MPP1	1	INTEGER	MP+1
MMAX	1	INTEGER	Maximum gravity row number for run
NMAX	6	INTEGER	Maximum gravity element in I-1 row
NZERO	1	INTEGER	No elements in U0

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
NZROM2	1	INTEGER	No elements -2 in U0
N1M2	1	INTEGER	No elements -2 in U1
N2M2	1	INTEGER	No elements -2 in U2
N3M2	1	INTEGER	No elements -2 in U3
N4M2	1	INTEGER	No elements -2 in U4
N5M2	1	INTEGER	No elements -2 in U5
N6M2	1	INTEGER	No elements -2 in U6
NDUO	1	INTEGER	No elements in DUO
NDU1	1	INTEGER	No elements in DUL
NDU2	1	INTEGER	No elements in DU2
NDU3	1	INTEGER	No elements in DU3
NDU4	1	INTEGER	No elements in DU4
NDU5	1	INTEGER	No elements in DU5
NO	1	INTEGER	Number of elements in CO (Gravity row)
N1	1	INTEGER	Number of elements in 1 (Gravity row)
N2	1	INTEGER	Number of elements in 2 (Gravity row)
N3	1	INTEGER	Number of elements in 3 (Gravity row)
N4	1	INTEGER	Number of elements in 4 (Gravity row)
OPTION	20	LOGICAL	Array of option switches
ORBEL	1	LOGICAL	Logical test (integration of orbital elements if true)

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
ERROR	1	LOGICAL	Input error halt flag
NCAPB	1	LOGICAL	Not used
TSTN1	1	LOGICAL	True if no general terms for U1
TSTN2	1	LOGICAL	True if no general terms for U2
TSTN3	1	LOGICAL	True if no general terms for U3
TSTN4	1	LOGICAL	True if no general terms for U4
TSTN5	1	LOGICAL	True if no general terms for U5
TSTN6	1	LOGICAL	True if no general terms for U6
TSTM3	1	LOGICAL	True if U3 not calculated
TSTM4	1	LOGICAL	True if U4 not calculated
TSTM5	1	LOGICAL	True if U5 not calculated
TSTM6	1	LOGICAL	True if U6 not calculated
TSTM7	1	LOGICAL	True if U7 not calculated
TSTDU2	1	LOGICAL	True if DU2 is not to be calculated
TSTDU3	1	LOGICAL	True if DU3 is not to be calculated
TSTDU4	1	LOGICAL	True if DU4 is not to be calculated
TSTDU5	1	LOGICAL	True if DU5 is not to be calculated
TSTDU6	1	LOGICAL	True if DU6 is not to be calculated
TST1	1	LOGICAL	True if row 1 of the forces is not calculated
TST2	1	LOGICAL	True if row 2 of the forces is not calculated
TST3	1	LOGICAL	True if row 3 of the forces is not calculated
TST4	1	LOGICAL	True if row 4 of the forces is not calculated
TST5	1	LOGICAL	True if row 5 of the forces is not calculated

MISS COMMON DEFINITIONS

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
TFINAL	1x2	DOUBLE	Final time for current interpolation polynomial coefficients for the rotation and position matrices
TMID	1x2	DOUBLE	Base time for current interpolation polynomial coefficients for the transformation matrices
PXE	(3x9)x2	DOUBLE	Coefficients for earth vector evaluation
PXS	(3x9)x2	DOUBLE	Coefficients for sun vector evaluation
PECCTR	(3x3x5)x2	DOUBLE	Coefficients for rotation matrix evaluation
TSTIME	1x2	DOUBLE	Current time in seconds from run start, equals TIME unless year crossover has occurred
RADSUN	4x2	DOUBLE	Combined radiation pressure and sun forces
THRTRM	(3x3x2)x2	DOUBLE	Impulse forces derived from card input thrust parameters
MOON2	1x2	DOUBLE	Moon radius, squared
DTSQR	1x2	DOUBLE	Integration timestep, squared
DFDRAD	3x2	DOUBLE	Radiation pressure partials
IRDFLG	1	INTEGER	Pointer for radiation pressure parameters
IRDSUN	1	INTEGER	Pointer for radiation pressure parameters
ITHR	1	INTEGER	Pointer for thrust parameters

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
ITFLAG	1	INTEGER	Pointer for thrust parameters
NGRVP1	1	INTEGER	Number of gravity parameters plus one
YRCRSS	1	LOGICAL	Indicates year if crossover has occurred
FLAG	1	LOGICAL	Radiation pressure parameter flag
THRPRM	1	LOGICAL	Indicates if thrust parameters from input cards are present
THRSTP	1	LOGICAL	Indicates if a thrust parameter, from input cards, occurs in current timestep

PERM COMMON DEFINITIONS

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
TIME	1x2	DOUBLE	Time of current time step, seconds from current year
GRAVMN	1x2	DOUBLE	Gravity constant of Moon
GRAVEH	1x2	DOUBLE	Gravity constant of Earth
GRAVSN	1x2	DOUBLE	Gravity constant of Sun
RMOON	1x2	DOUBLE	Radius of Moon (KM)
PI	1x2	DOUBLE	PI
CSPEED	1x2	DOUBLE	Velocity of light
H1	1x2	DOUBLE	Mean hour angle of Greenwich at beginning of arc year
H2	1x2	DOUBLE	Mean hour angle of Greenwich at beginning of 2nd year
SMASS	1x2	DOUBLE	Satellite mass
SAREA	1x2	DOUBLE	Satellite area
GAMMA	14x2	DOUBLE	A-C coefficient. LCD in MX+2
ALPHA	14x2	DOUBLE	A-C coefficient. LCD in MX+2
ALPHAD	1x2	DOUBLE	LCD for Alphas
GAMMAD	1x2	DOUBLE	LCD for Gammas
GAMMA1	1x2	DOUBLE	GAMMA1/GAMMAD
XZERO	3x2	DOUBLE	Starting coordinates
XDOTO	3x2	DOUBLE	Starting velocities
RTIME	3x2	DOUBLE	Time span for radiation parameter value
RPARAM	3x2	DOUBLE	Value of radiation pressure value

<u>MNEMONIC</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
TTIME	2x2	DOUBLE	Time of thrust force (Seconds from beginning of year)
TTAU	2x2	DOUBLE	Length of thrust force (Seconds)
TFORCE	2x2	DOUBLE	Temporary storage
TX	(3x2)x2	DOUBLE	Direction of thrust force (Moon fixed coordinates)
YRSECS	1x2	DOUBLE	Number of seconds in start year
DELTAI	1x2	DOUBLE	Seconds in A-C time step
DELTAT	1x2	DOUBLE	Seconds in tape time step
DELGL	1x2	DOUBLE	Seconds I Gill time step
TZERO	1x2	DOUBLE	Time of start (Seconds from year beginning)
C0	(11x2)x2	DOUBLE	Gravity coefficients 0th row
C1	(9x2)x2	DOUBLE	Gravity coefficients 1st row
C2	(7x2)x2	DOUBLE	Gravity coefficients 2nd row
C3	(5x2)x2	DOUBLE	Gravity coefficients 3rd row
C4	(3x2)x2	DOUBLE	Gravity coefficients 4th row
C5	(1x2)x2	DOUBLE	Gravity coefficients 5th row
GRAV	75x2	DOUBLE	Values for all parameters
LABGRV	75	INTEGER	Labels for all parameters

START COMMON DEFINITIONS

MNEMONIC	# of WORDS	FORMAT	CONTENTS
FZERO	(3x75)x2	DOUBLE	Gill initial FORCE array
VO	(3x75)x2	DOUBLE	Gill initial velocity array
XO	(3x75)x2	DOUBLE	Gill initial position array
S1	3x2	DOUBLE	Gill variable array
F1	3x2	DOUBLE	Gill variable array
S2	3x2	DOUBLE	Gill variable array
X	3x2	DOUBLE	Gill variable array
Q	3x2	DOUBLE	Gill variable array
V	3x2	DOUBLE	Gill variable array
JACOB	(3x3x3)x2	DOUBLE	Stored DFDX arrays for Gill
PPHI	(3x75x3)x2	DOUBLE	Stored PF arrays for Gill
NIPPI	1	INTEGER	Number of gravity parameters plus one

SECTION IV
SUBROUTINE WRITE-UPS

NAME	MAIN	
PURPOSE	MAIN control program for integration	
CALLS	INPUT	Processes card input
	FMRS	Initializes ephemeris and impulse tapes
	TRNSFM	Initializes earth, sun and rotation data for FORCES
	TRAGIC	Initializes Forces and does starting procedure integration
	CADCON	Control program for MAIN procedure integration
INPUT	See card input	
OUTPUT	Trajectory and perturbation tape	
TAPES	USED	18 Trajectory tape - output 19 Ephemeris tape - input 28 Impulse tape - input 29 Scratch ephemeris tape
NOTES	MAIN zeroes out commons and rewinds tapes before starting the calling sequence.	

NAME	CAD
PURPOSE	Performs the actual main procedure integration
METHOD	The integration is done using a twelfth order predictor-corrector Adams-Cowell method.
CALLED BY	CADCON Control program for the main procedure integration
CALLS	FORCES Force routine for integration INVERT Matrix inversion routine
INPUT	XSAT Satellite position FORCE Force on satellite DX Impulse forces, from tape THRTRM Thrust parameter forces
OUTPUT	For the current TIME: XSAT Satellite position FORCE Force on satellite P Perturbations

NAME	CADCON	
PURPOSE	Control routine for main integration procedure. It sets up the loops for calling the integration routine CAD and writes the trajectory and perturbations on the trajectory tape.	
CALLED BY	MAIN	Control program for integration
CALLS	TRNSFM	Gets rotation matrix and earth and sun positions
	CAD	Adams-Cowell integration routine
INPUT	TIME	Time of current integration step
	DELTAI	Integration time step length (sec.)
	MX	Order of integration
	XSAT	Satellite position
	FORCE	Force on satellite
	P	Perturbations
	NUMSTP	Number of tape time steps to be recorded
	INMULT	Number of integration steps per tape step
OUTPUT	Trajectory tape containing XSAT, FORCE, P for current time step	
TAPES	USED	18 Writes entire integration on 18. The trajectory tape 18 is then rewound.

NAME	DFDXJ
PURPOSE	Calculates the contribution to the Jacobian of the forces with respect to the satellite coordinates and places the partials of the force with respect to the gravity parameters in the array PERTS, for the j^{th} row of the gravity array.
METHOD	The DFDX contributions are calculated by a recursion formula for the gradient-gradient of the potential.
CALLED BY	FORCES force routine for integration
INPUT	DUI $j-1^{\text{st}}$ row of DU (Gradient of potential) DUJ j^{th} row of DU DUM $j+1^{\text{st}}$ row of DU CJ j^{th} row of gravity coefficients (C&S) L counter for placing elements into PERTS NFIRST number of first element in row j NLAST number of last element in row j TERM1 multiplier term I dimension of row $j-1$ J dimension of row j M dimension of row $j+1$ A multiplier array IADD displacement of S partials into PERT array.
OUTPUT	DFDX jacobian of forces with respect to satellite position. PERT array of partials with respect to gravity parameters.

NOTES

DFDXJ is not called for the zero row.

NAME	DUJS	
PURPOSE	Calculates the gradient of the potential for the j^{th} row of gravities.	
METHOD	Evaluates a recurrence relation for the gradient of the potential.	
CALLED BY	FORCES	Force program for integration
INPUT	UI, VI, I	$j-1^{\text{st}}$ row of U and V and its dimension
	UM, VM, M	j^{th} row of U and V and its dimension
	UJJ, VJJ, JJ	$j+1^{\text{st}}$ row of U and V and its dimension
	NLAST	number of elements in DUJ row
	A	multiplier array
OUTPUT	DUJ	Gradient of potential for j^{th} row of gravities.

NAME FMERR

PURPOSE Writes error message and number from FMRS routine.

CALLED BY FMRS

INPUT ITT error number.

OUTPUT Writes error message RUN WAS STOPPED BECAUSE OF EPHEMERIS TAPE
ERROR and error number.

ERROR CHECKS

1400	should be 400 record type on ephemeris tape.
1401	year of ephemeris tape not equal to start year of run.
1402	ephemeris data doesn't span run or last days of run not on tape.
1410	should be 410 record type on ephemeris tape.
1411	ephemeris time and program time don't match.
1700	Impulse header record type not 100.
1701	satellite numbers of impulse tape and run don't match.
1702	Impulse data record type not 110.

NAME	FMRS	
PURPOSE	FMRS reads necessary data from input ephemeris tape and transfers it to a scratch tape for use in the integration program and to the trajectory tape for the normal equations. It then rewinds the scratch tape and reads the first record. FMRS also initializes the impulse tape.	
CALLED BY	MAIN	main control program for integration
CALLS	FMERR	error routine for FMRS
INPUT	ISYR	start year of run
	ISDAY	start day of run
	IDAYS	number of days in run
	ISATNO	satellite number
	TIME	time of first integration start
OUTPUT	TMID	base time for polynomials
	PXE	polynomial for earth position
	PXS	polynomial for sun position
	PECDTR	polynomial for rotation matrix
	TFINAL	last time for polynomials
	VTIME	time of first impulse for run
	V	first impulse of run

TAPES	USED	
	19	ephemeris tape. Reads necessary data for run and writes it on 18 and 29. Then 19 is rewound.
	29	Scratch ephemeris tape.
ERROR CHECKS	1400	should be 400 record type on ephemeris tape.
	1401	year of tape not equal to start year of run.
	1402	ephemeris data doesn't span run.
	1410	should be 410 record type on ephemeris tape.
	1411	ephemeris time and program time don't match run satellite number.
	1700	impulse header record type not equal to 100.
	1701	satellite number on impulse tape doesn't match run satellite number.
	1702	impulse data record type not equal to 110.

NAME	FORCES	
PURPOSE	Calculates the force, partials of the force with respect to the parameters and the partials of the force with respect to the satellite coordinates.	
METHOD	Rotates satellite coordinates to moon fixed frame, calculates the moons potential in terms of spherical harmonics at that point by use of a recurrence relation, and uses similar techniques to get the derivatives from the potential. After values are calculated in the moon fixed frame they are rotated back to the inertial frame.	
CALLED BY	SFORCE	Force program for starting procedure
	CADCON	Control program for main procedure
CALLS	DUJS	Calculates DU values for each row.
	DFDXJ	Calculates contributions to DFDX and places partials into PERTS
	NOMOON	Calculates Force and DFDX contributions from sun, earth, and radiation pressure.
INPUT	XSAT	satellite position in inertial frame
	C1	gravity coefficients
	C2	gravity coefficients
	C3	gravity coefficients
	C4	gravity coefficients
	C5	gravity coefficients

OUTPUT	FORCE	Force exerted on satellite.
	DFDX	Jacobian of forces wrt satellite position.
	PF	Partials of force wrt integration parameters.

NAME	GILT	
PURPOSE	Integrate the first MX time steps which are used to start the main integration procedure	
METHOD	The integration is done by a simplified Gill method.	
CALLED BY	TRAGIC	Control program for starting procedure
CALLS	SFORCE	Calculates necessary forces and transfers data to main procedure arrays and trajectory tape.
INPUT	XO	Initial coordinates (trajectory and perturbations)
	VO	Initial velocities (trajectory and perturbations)
	NSPTS	Number of starting procedure time steps
	DELTAG	Starting procedure time step length (sec)
	NIPPL1	Total number of parameters plus one
OUTPUT	XSAT	Satellite position
	FORCE	Force on satellite
	P	Perturbations
		Trajectory tape containing XSAT, FORCE, and P if any tape stores were required during the starting procedure
NOTES	1. The subroutine treats the integration of trajectory and perturbations the same. All differences are in the forces calculated by SFORCE.	

2. All initial conditions except those for the trajectory and initial conditions or orbital elements are zero. Those for the trajectory are input; those for the i.c. or o.e. are calculated by INTPAR.

NAME	GIN	
PURPOSE	Reads the gravity parameter cards and generates the gravity label array.	
CALLED BY	INPUT	Processes card input.
CALLS	INPERR	Error routine for card input.
INPUT	See card input, cards 200 through 299.	
OUTPUT	C0, C1, C2, C3, C4, and C5. These are the gravity parameter arrays	
	GRAV	Gravity parameters in standard sort
	LABGRV	Gravity parameter labels
ERROR CHECKS	GIN checks the input for consistancy, and checks for illegal input. See the write up of INPERR for a list of the actual error messages printed.	

NAME	INPERR	
PURPOSE	Writes input error message and error number	
CALLED BY	INPUT	Main input routine
	GIN	Gravity input routine
INPUT	K	Error number
ERROR CHECKS	201	200 card out of order (GIN)
	202	$M_{MAX} < 0$
	203	$N_{MAX}(1) > 10$
	204	Row of gravity array defined longer than dimensioned
	205	Row i longer than row i-1
	206	210 card out of order
	207	Gravity coefficient M greater than defined MMAx
	208	Gravity coefficient N greater than defined $N_{MAX}(M+1)$

All other numbers indicate that the program was looking for the card with that number and could not find it in order.

NAME	INPUT
PURPOSE	Reads input data, prepares the data for the integration, sets up labels and associated parameters for communication with NORMEQ and SOLVE, prints edit of input data and option, and writes part of the header of the trajectory tape.
CALLED BY	MAIN control program for integration
CALLS	GIN gravity input processor
	STATE orbital element, initial condition conversion and partials.
	INPERR error routine for card input
INPUT	All card input
OUTPUT	Modified card input
TAPES	18 Header of trajectory tape is written as well as record of labels and their associated parameters.
ERROR CHECKS	Error routine prints out error numbers for errors which occur as the input routine, which expects cards in a given sequence, finds a card missing from the sequence. The error number is that of the expected card. (For errors in the 200-299 range see subroutine GIN.)

NAME	INTPAR	
PURPOSE	Calculates partials of initial conditions with respect to orbital elements or initial conditions.	
CALLED BY	STATE	control program for conversions
INPUT	XER	initial position of satellite
	XDOTZ	initial velocity of satellite
	PZ	values from ORBTOX
	ERB	orbital elements
	GMU	moon gravity constant
	ORBUSE	logical flag; compute partials of initial conditions with respect to orbital elements if true; partials of initial conditions with respect to initial conditions otherwise.
OUTPUT	ORBP AZ	partials of satellite position with respect to orbital elements.
	ORBDOZ	partials of satellite velocity with respect to orbital elements.
NOTES	If ORBUSE is false a sample "unit" vertex is generated.	

NAME	INVERT (A,N)	
PURPOSE	Inverts the NxN matrix A	
METHOD	Crout reduction with no pivot search	
CALLED BY	CAD	
INPUT	A	matrix to be inverted
	N	order of matrix A
OUTPUT	A	the inverse of the input matrix A

NAME	NOMOON (PERTSS)	
PURPOSE	Calculates forces and contribution to Jacobian of forces wrt satellite coordinates from the sun and earth gravity and from the radiation pressure. It also calculates the partial of the force with respect to the radiation pressure parameter.	
CALLED BY	FORCES	Force routine for integration
INPUT	PERTSS	logical flag for calculation of Jacobian (indicates perturbations are being calculated)
	XSAT	satellite position
	SUNPOS	sun position
	EPOS	earth position
	IRDSUN	counter to indicate proper element of RADSLUN
	RADSLUN	combine radiation pressure and sun gravity coefficients
	GRAVEH	earth gravity coefficient
OUTPUT	EXTRAF	forces from NOMOON
	EXDFDX	jacobian contribution from NOMOON
	DFDRAD	partial of forces with respect to radiation pressure parameter
NOTES	A test for the possibility of the satellite being in the moon's shadow is performed. If so, DFDRAD=0 and there is no contribution to EXTRAF or EXDFDX from the radiation pressure.	

NAME	ORBTOX	
PURPOSE	Transforms orbital elements to initial conditions and computes values for use in INTPAR.	
CALLED BY	STATE	control program for conversions.
INPUT	ERB	orbital elements
	GMU	moon gravity constant
	ORBIN	true implies orbital element input; false, initial conditions.
OUTPUT	XFR	initial coordinates of satellite
	XDOTZ	initial velocities of satellite
	PZ	array of values for INTPAR
ERROR CHECKS	If iteration for PHI fails to converge, the message NON CONVERGENCE FOR PHI is printed and the run is stopped.	
NOTES	<ol style="list-style-type: none">1. If initial conditions need not be calculated only the first sections of the program are executed, those necessary to provide the input data for INTPAR.2. Several sets of equivalances are necessary because of previous definitions in the routine.	

NAME	SFORCE	
PURPOSE	Provides the proper forces for the Gill integration at each time step, stores starting data for the main integration procedure and writes trajectory and perturbation records for each tape time step.	
CALLED BY	GILT	Routine for starting integration
CALLS	FORCES	Force routine for integration
	TRNSFM	Rotation and earth and sun position routine
INPUT	IPARUM	Number of parameters being integrated
	ICYCLE	Gill cycle for this parameter
	ITMSTP	Starting procedure time step for this run
	XSAT	Satellite position
	FORCE	Force on satellite
	PF	Partials of force with respect to parameters
	DFDX	Partials of force with respect to satellite coordinates
OUTPUT	F1	Force for gill step for 2 nd , 3 rd , or 4 th cycle for 1 parameter
	FZERO	Force for gill for first gill cycle for all parameters
	XSAT	Starting satellite positions for main integration
	FORCE	Starting satellite forces for main integration
	P	Starting perturbations for main integration
	PHI	Starting perturbational forces for main integration

NAME	STATE	
PURPOSE	Control program for conversion of initial conditions to orbital elements and vice versa and for calculation of starting array of arc partials.	
CALLED BY	INPUT	Input program for integration
CALLS	ORBTOX	Computes initial conditions from orbital elements and prepares values for INTPAR
	XTOORB	Computes orbital elements from initial conditions.
	INTPAR	Calculates partials of initial conditions with respect to orbital elements or initial conditions.
INPUT	ORBIN	True implies orbital elements input; false, initial conditions.
	ORBUSE	True implies orbital elements output; false, initial conditions.

NAME TRAGIC

PURPOSE Sets up logical constant and multiplier arrays for routine
 FORCES and acts as control routine for integration starting
 procedure.

CALLED BY MAIN control program for integration
 GILT starting procedure for integration

INPUT XZERO initial satellite coordinates
 XDOTO initial satellite coordinates
 NUMGA number of integration parameters
 PERTS true if perturbations are to be calculated
 MMAX maximum row in gravity array
 NMAX(I) maximum elements in I-1st row of gravity array

OUTPUT XO (K,1)
 VO (K,1)
 NZERO
 NZEROM2 N1M2 N2M2 N3M2 N4M2 N5M2 N6M2
 Number of elements in the ith row of U or V minus 2
 TSTN1 TSTN2 TSTN3 TSTN4 TSTN5
 Logical constants indicating fewer than three elements
 of the ith row if time of U or V are to be calculated
 TSTM3 TSTM4 TSTM5 TSTM6 TSTM7
 Logical constants which are true if the i-1st row
 is the last row of U or V to be calculated.

FACT1 $\frac{(N-1)!}{(N+1)!}$ for N=1, 12

FACT2 $\frac{(N-2)!}{(N+2)!}$ for N=2, 11

NDU0 NDU1 NDU2 NDU3 NDU4 NDU5

Number of elements to be calculated in the i^{th} row of DU.

TSTDU2 TSTDU3 TSTDU4 TSTDU5 TSTDU6

Logical constants which are true if the $i-1^{st}$ row is the last row of DU to be calculated.

NO N1 N2 N3 N4

Number of elements in the i^{th} row of the gravity array.

TST1 TST2 TST3 TST4 TST5

Logical constants which are true if the $(i-1)^{st}$ row is the last valid row of gravity constants.

A multiplier array for FORCES. $(A(K) = K*(K+1))$

FACT1 $\frac{(N-1)!}{(N+1)!}$ for N=1, 12

FACT2 $\frac{(N-2)!}{(N+2)!}$ for N=2, 11

NDU0 NDU1 NDU2 NDU3 NDU4 NDU5

Number of elements to be calculated in the i^{th} row of DU.

TSTDU2 TSTDU3 TSTDU4 TSTDU5 TSTDU6

Logical constants which are true if the $i-1^{\text{st}}$ row is the last row of DU to be calculated.

NO N1 N2 N3 N4

Number of elements in the i^{th} row of the gravity array.

TST1 TST2 TST3 TST4 TST5

Logical constants which are true if the $(i-1)^{\text{st}}$ row is the last valid row of gravity constants.

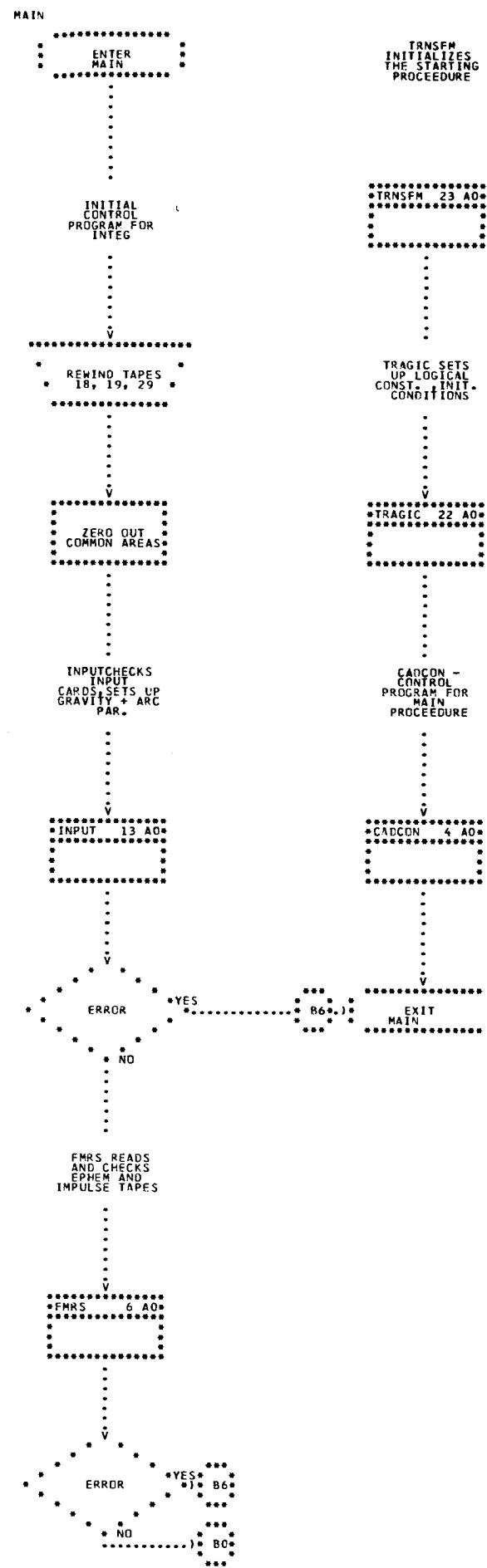
A multiplier array for FORCES. $(A(K) = K*(K+1))$

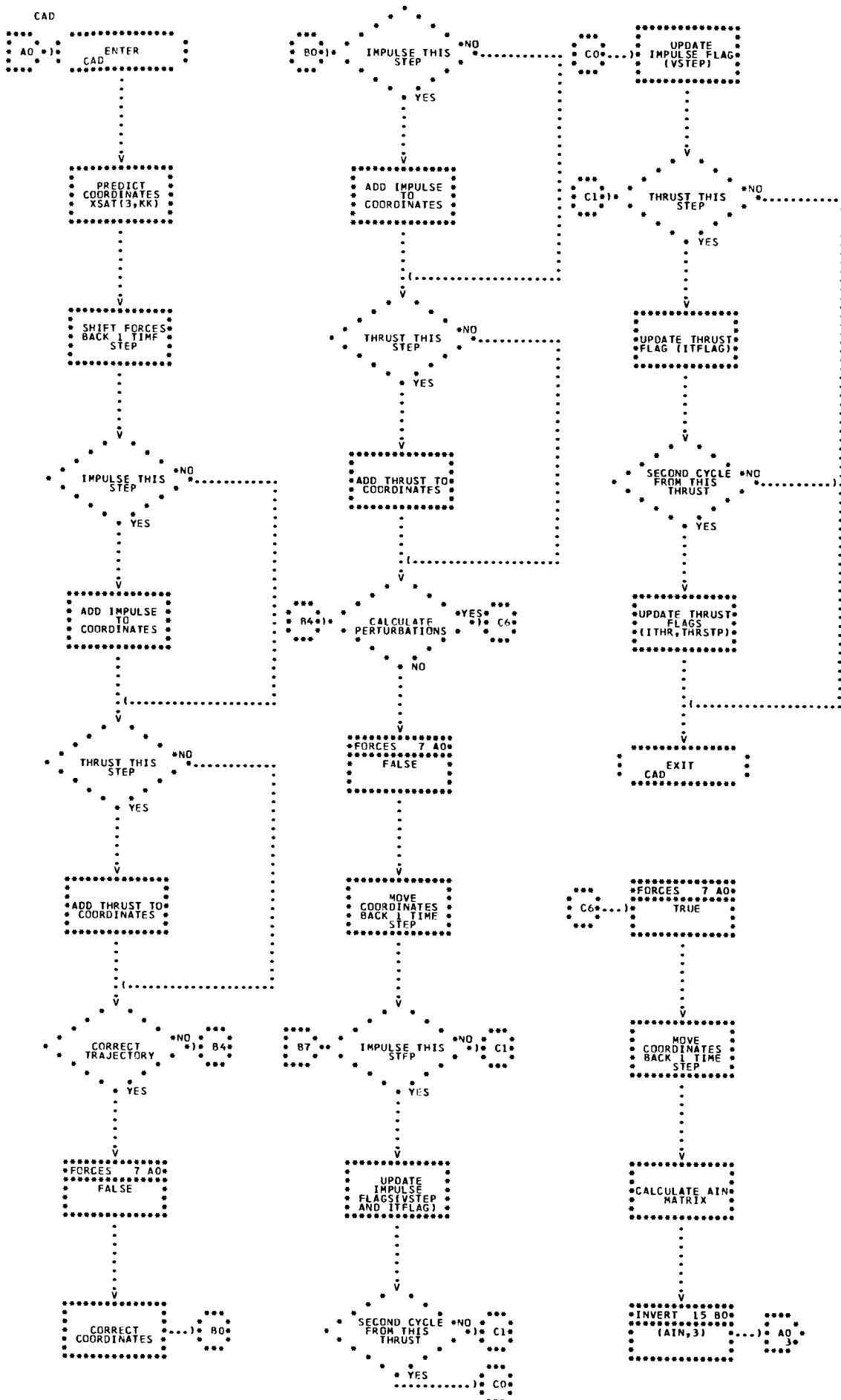
NAME	TRNSFM	
PURPOSE	Calculates the position of the sun and the earth with respect to the moon and the rotation matrix from moon fixed coordinates to moon equinox of 1950 Jan 1.0 from the ephemeris polynomial coefficients; keeps the proper ephemeris polynomial coefficients in core sets flags for contributions to the coordinates from the impulse tape, calculates those contributions and keeps the impulse tape positioned properly.	
CALLED BY	MAIN	Main control program for integration (initialization call)
	SFORCE	Force program for starting procedure
	CADCON	Control program for main integration procedure.
INPUT	TIME	Time of current step
	TFINAL	Final time for current interpolation polynomial coefficients
	TMID	Base time for current interpolation polynomial coefficients
	PXE	Coefficients for earth vector evaluation
	PXS	Coefficients for sun vector evaluation
	PECDT	Coefficients for rotation matrix evaluation
	IRDFLG	Counter for proper radiation pressure parameter

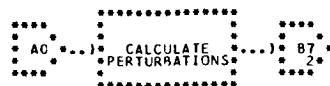
	NUMRAD	Number of proper radiation pressure parameter.
	THRPRM	Logical flag indicating thrust parameters.
	NUMTHR	Number of thrust parameters.
	VTAPE	Logical flag indicating presence of impulse tape.
	VTIME	Time of next impulse
	DELTAI	Time step for main integration
	V	Next impulse
OUTPUT	EPOS	Earth position
	SUNPOS	Sun position
	ROTATE	Rotation matrix (ECD) ^T
	IRDFLG	Counter for proper radiation pressure parameter
	ITFLAG	Counter for proper thrust step
	ITHR	Counter for proper thrust parameter
	THRSTP	Logical flag indicating impulse present for integration.
		Counter for proper impulse step
TAPES	USED	Logical flag indicating impulse present for integration.
	29	May read one ephemeris record
	28	May read one impulse record
NOTES	Contributions from thrust and impulse require addition to coordinates on two time steps.	

NAME	XTOORB	
PURPOSE	Calculates orbital elements from initial conditions.	
CALLED BY	STATE	Control program for conversion.
INPUT	XER	Initial satellite coordinate.
	XDOTZ	Initial satellite velocity.
	GMU	Gravity constant of moon (GRAVMN)
OUTPUT	ERB	Computed orbital elements
ERROR CHECK	If AI is greater than π , the message AI GREATER THAN PI is printed, and the run continues.	

SECTION V
FLOW CHARTS

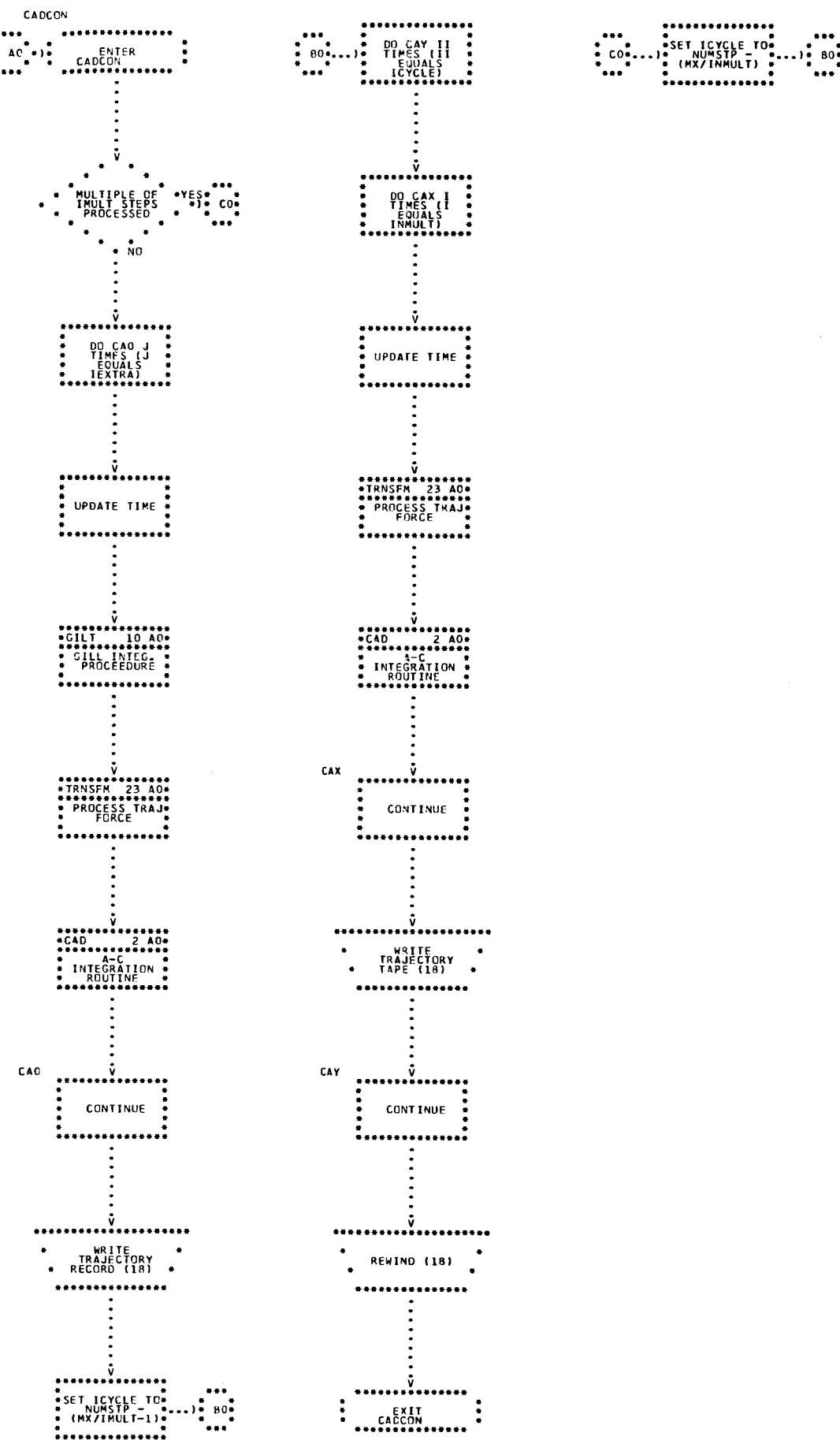






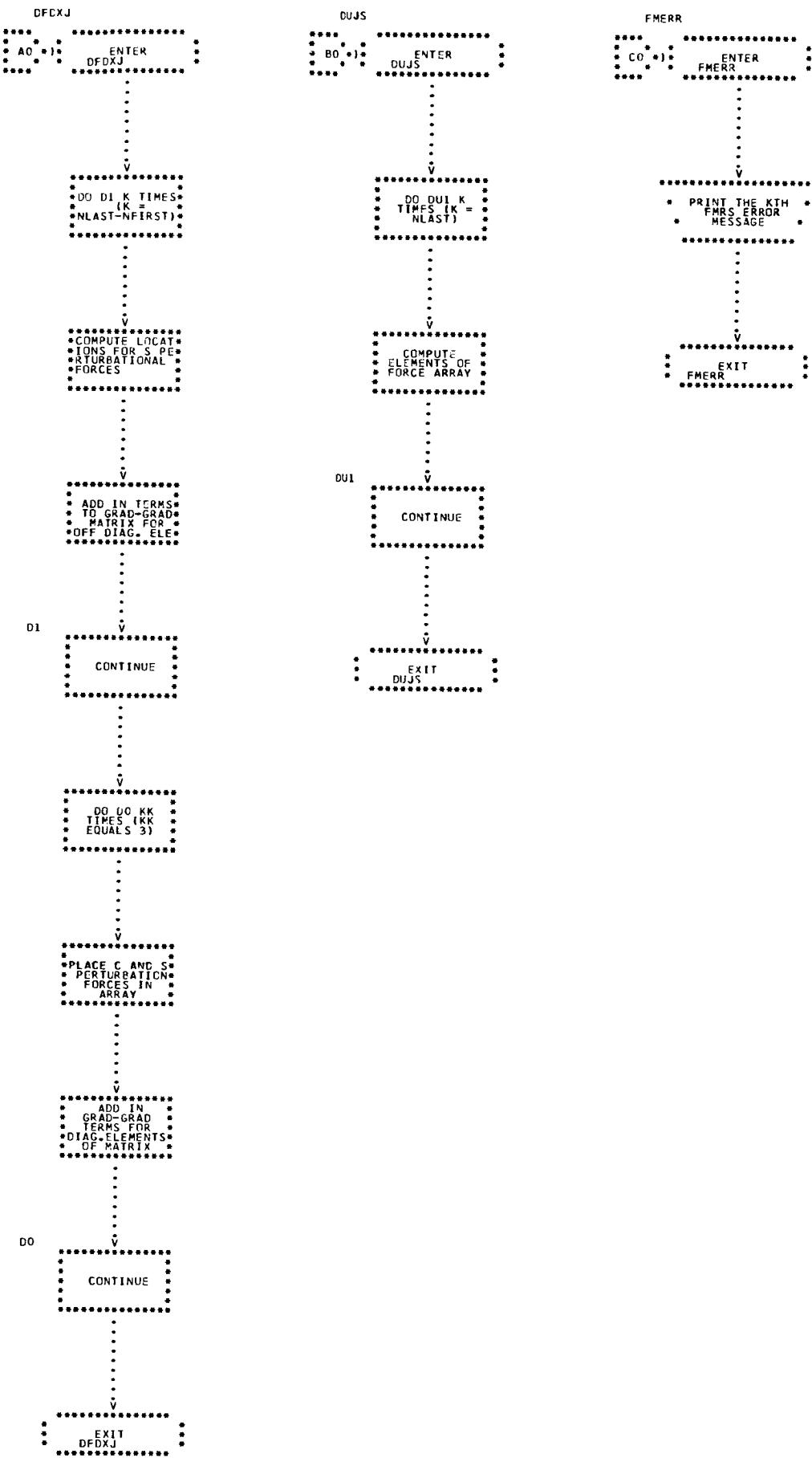
INTEGRATION PROGRAM FLOW CHARTS

4



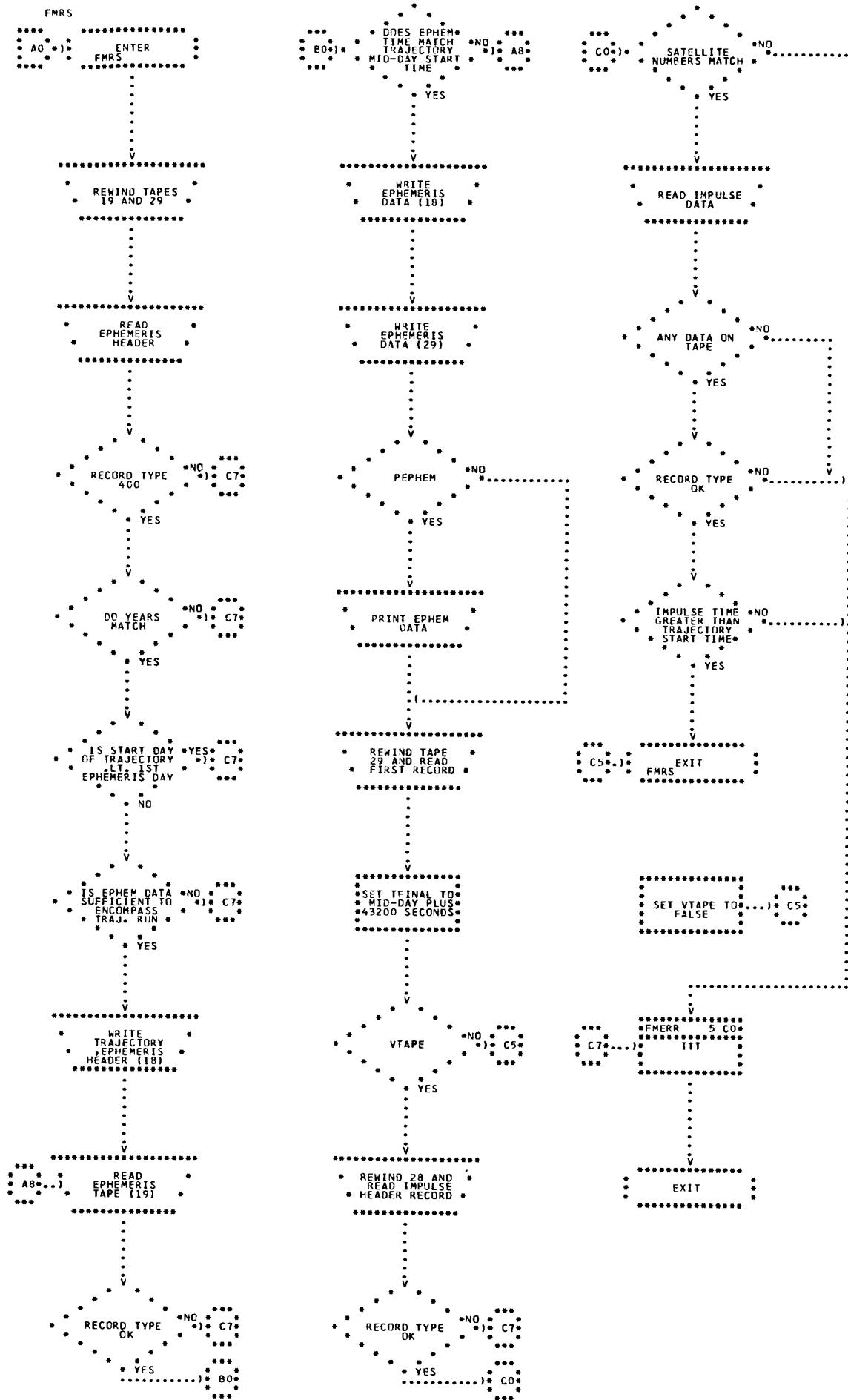
INTEGRATION PROGRAM FLOW CHARTS

3



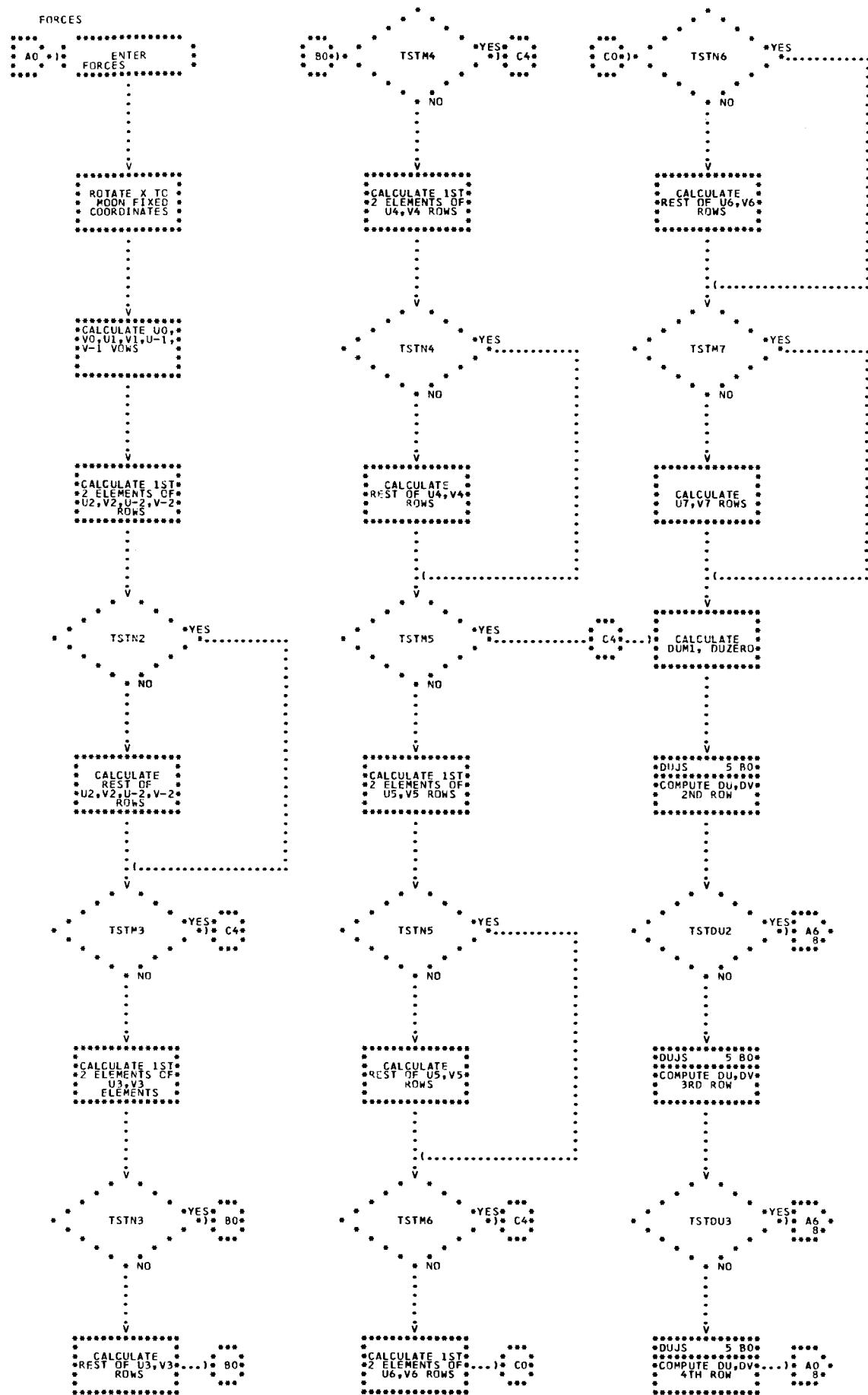
INTEGRATION PROGRAM FLOW CHARTS

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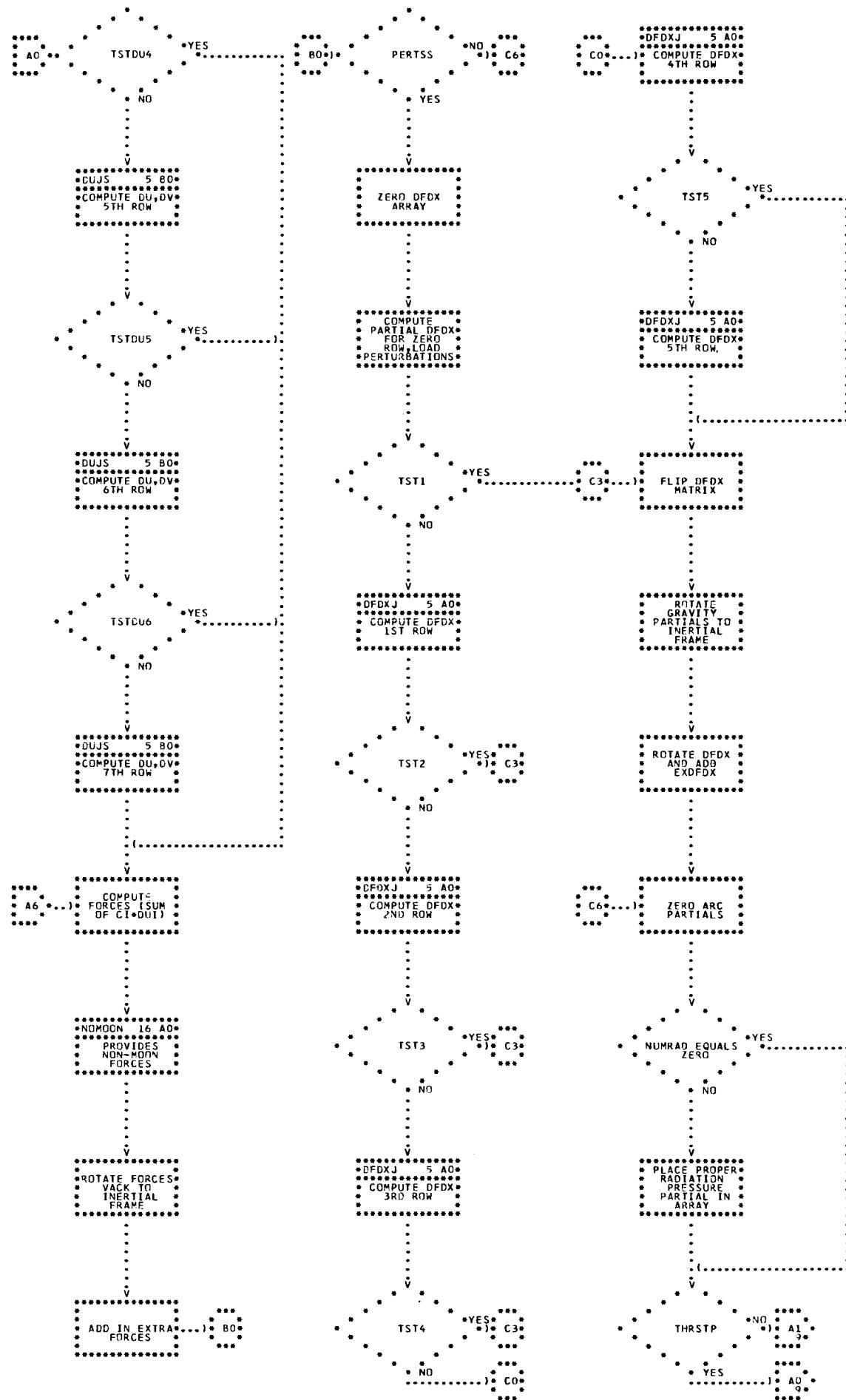
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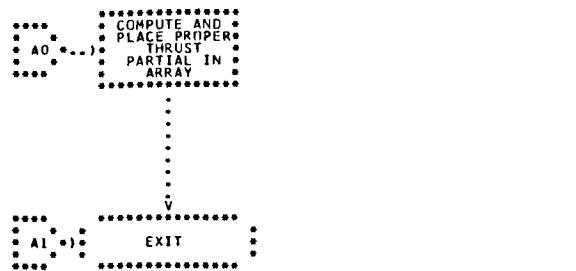
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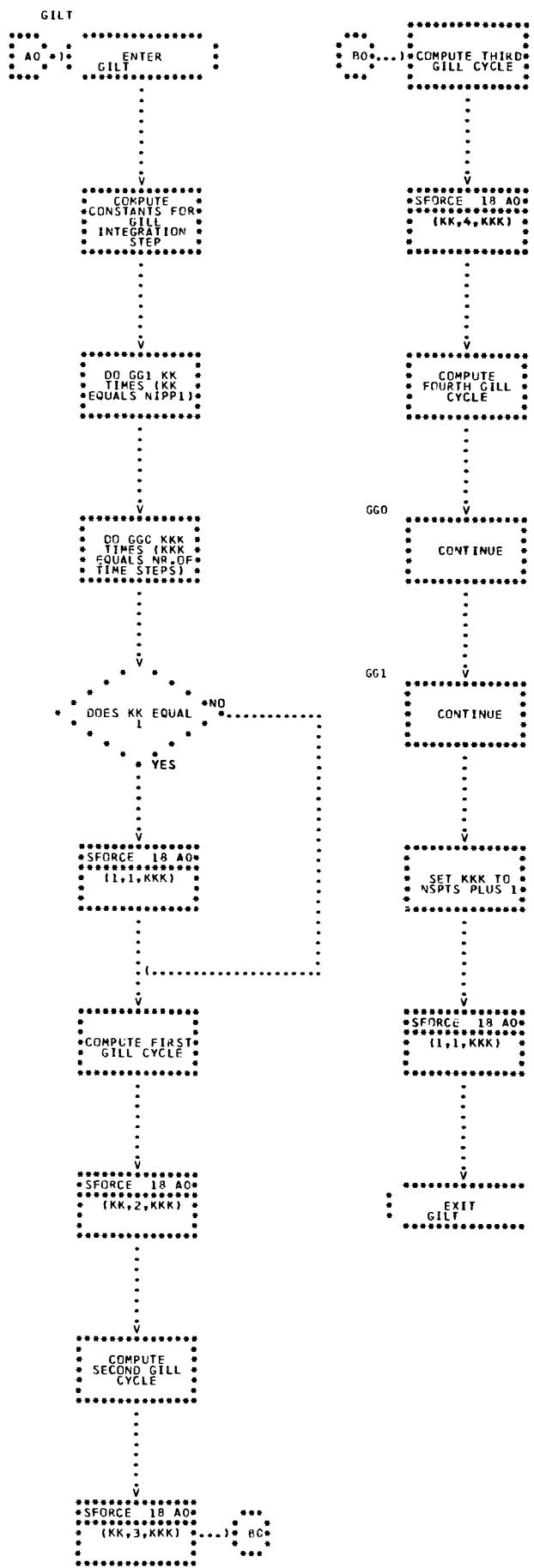


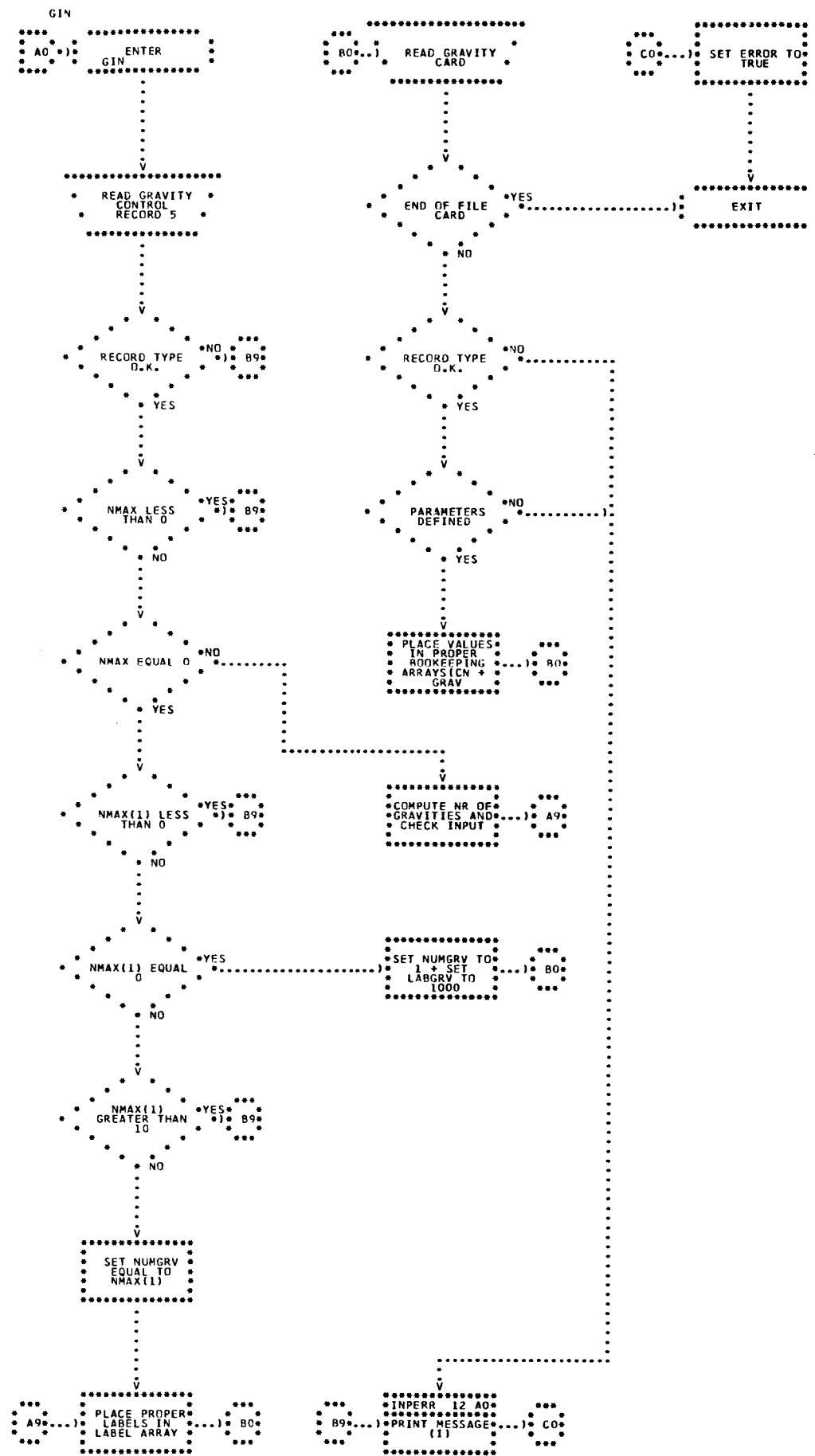
INTEGRATION PROGRAM FLOW CHARTS

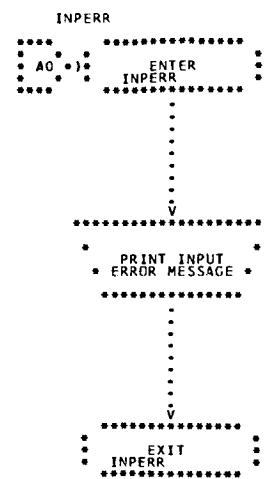
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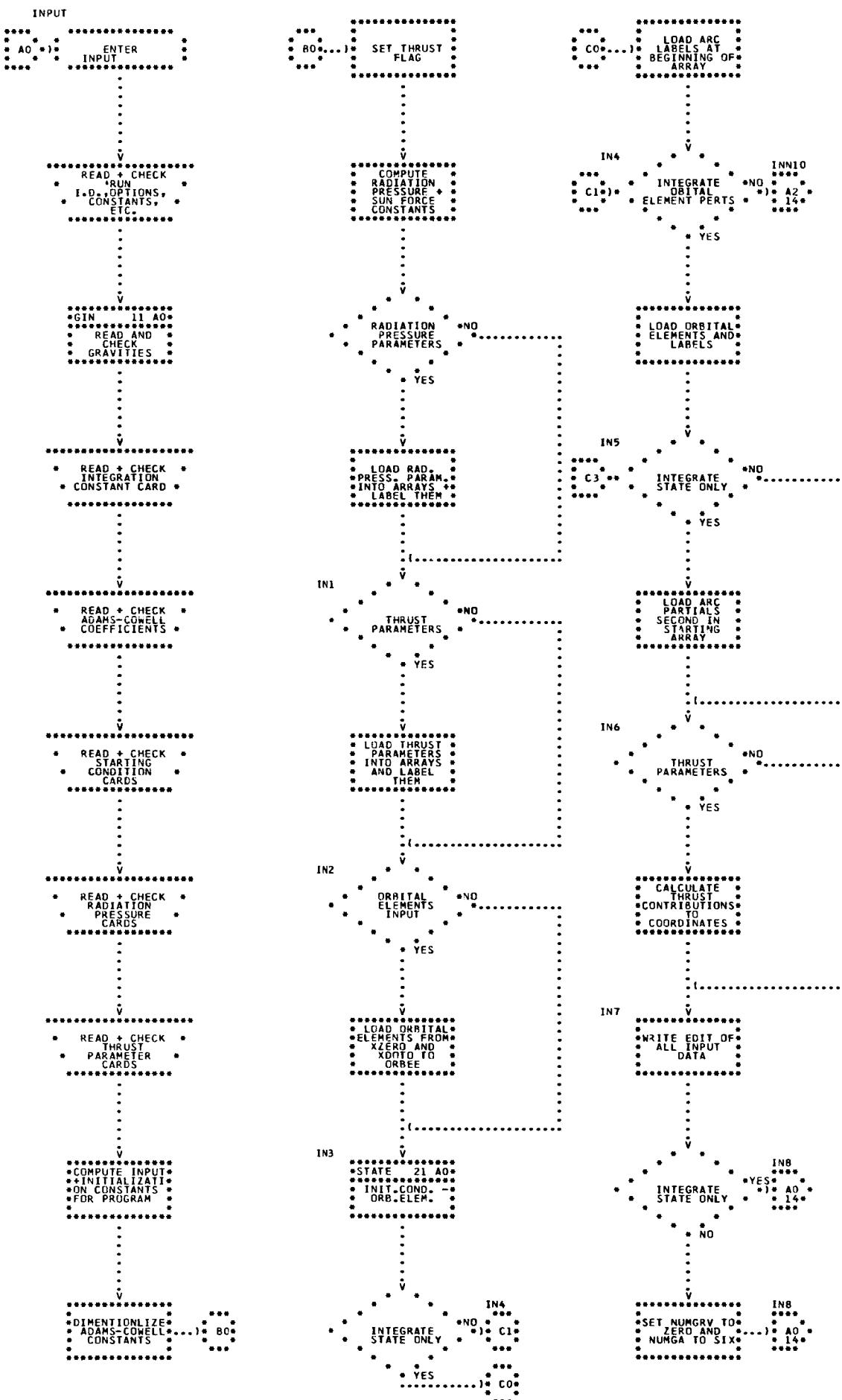


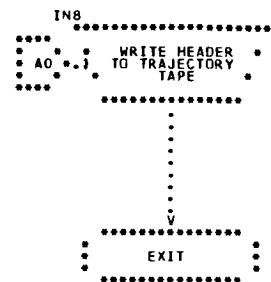


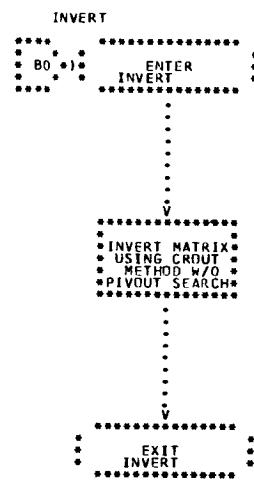
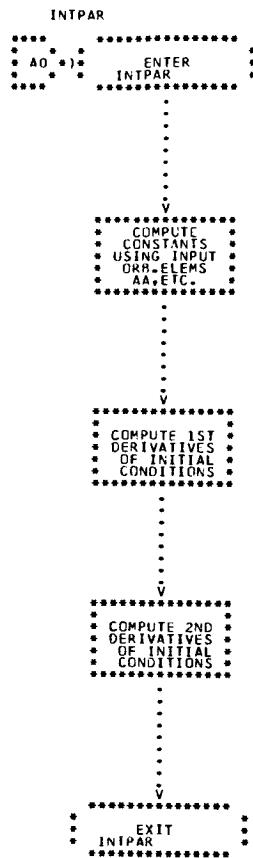


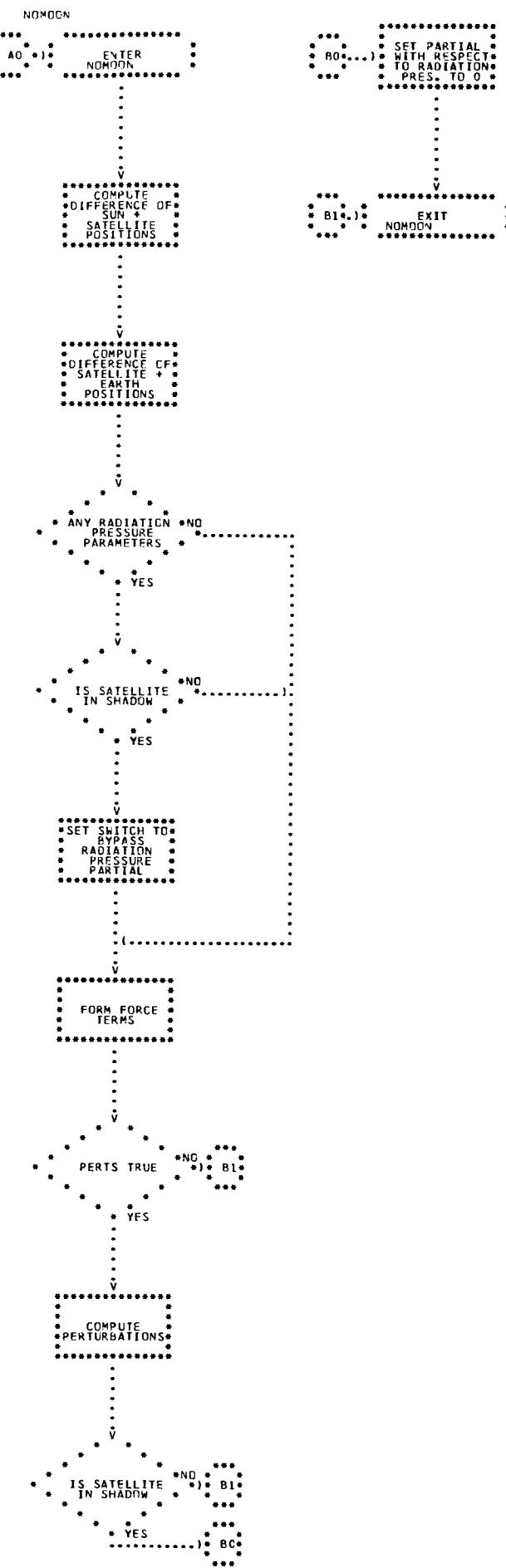


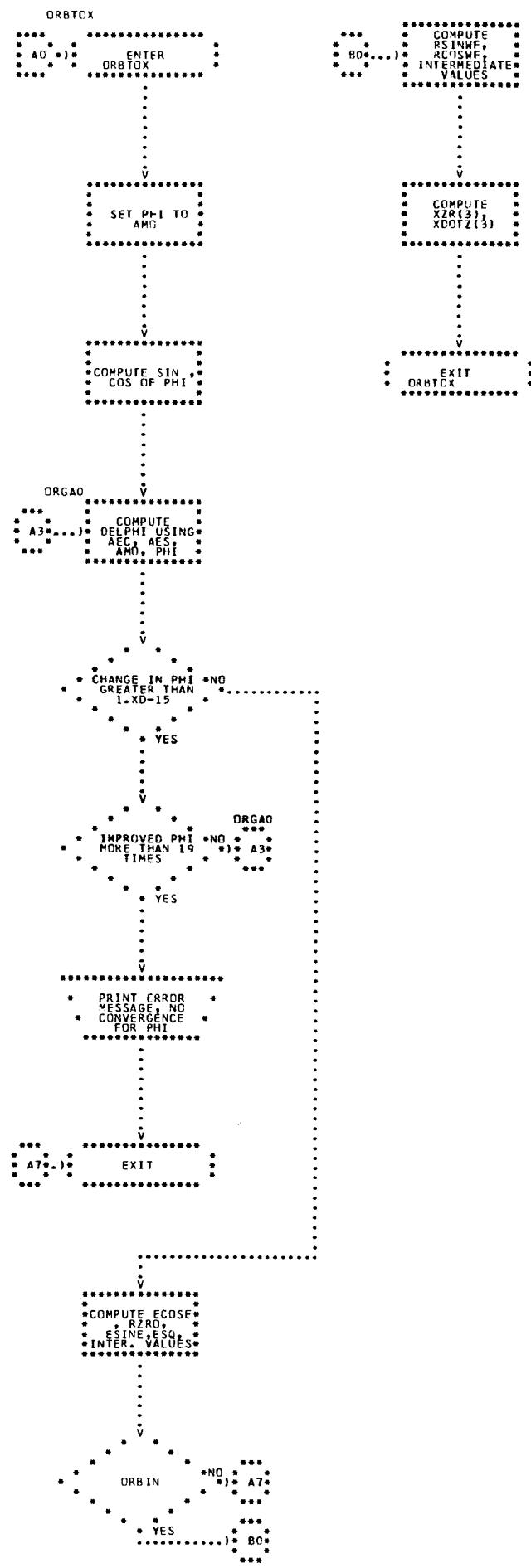


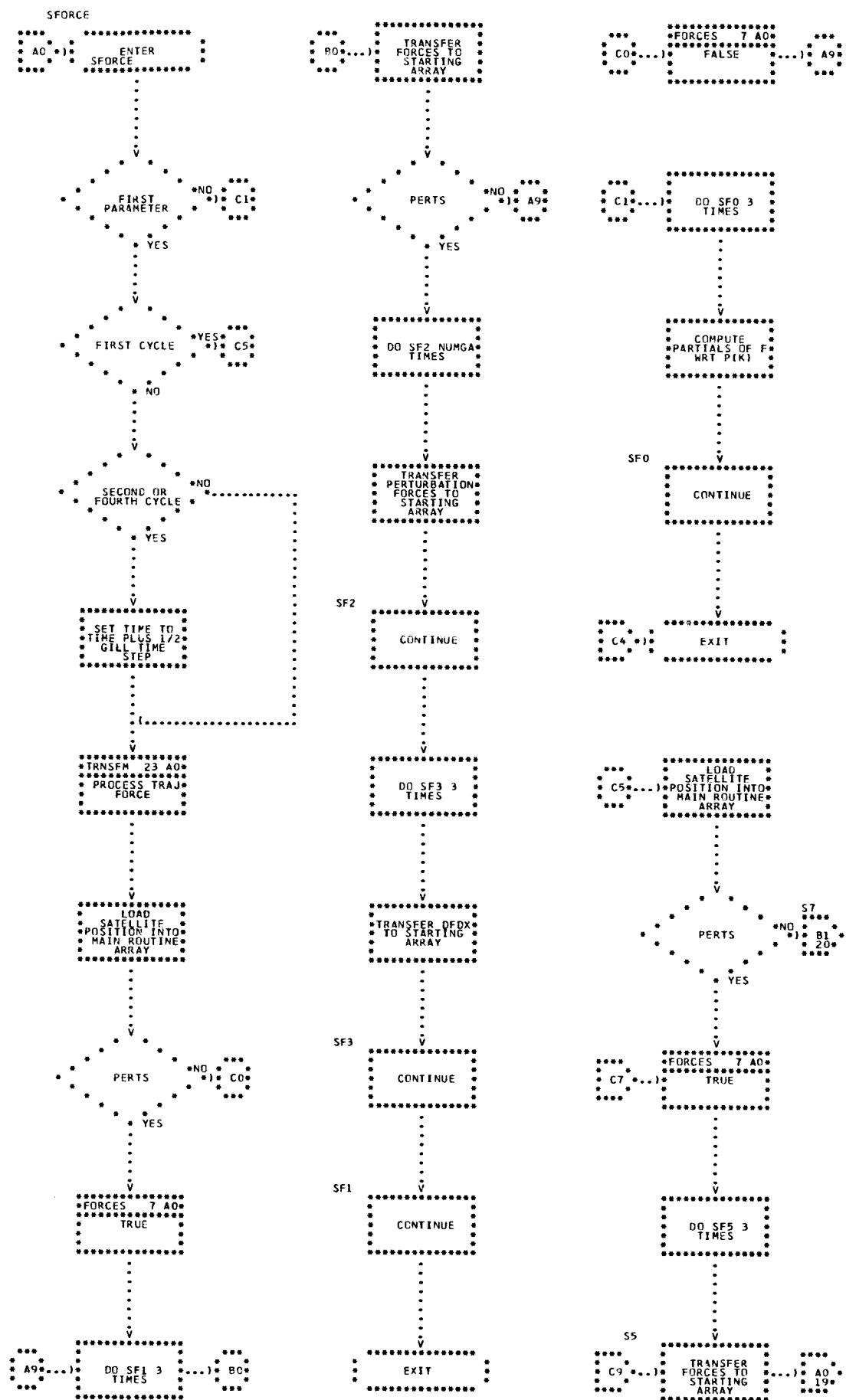


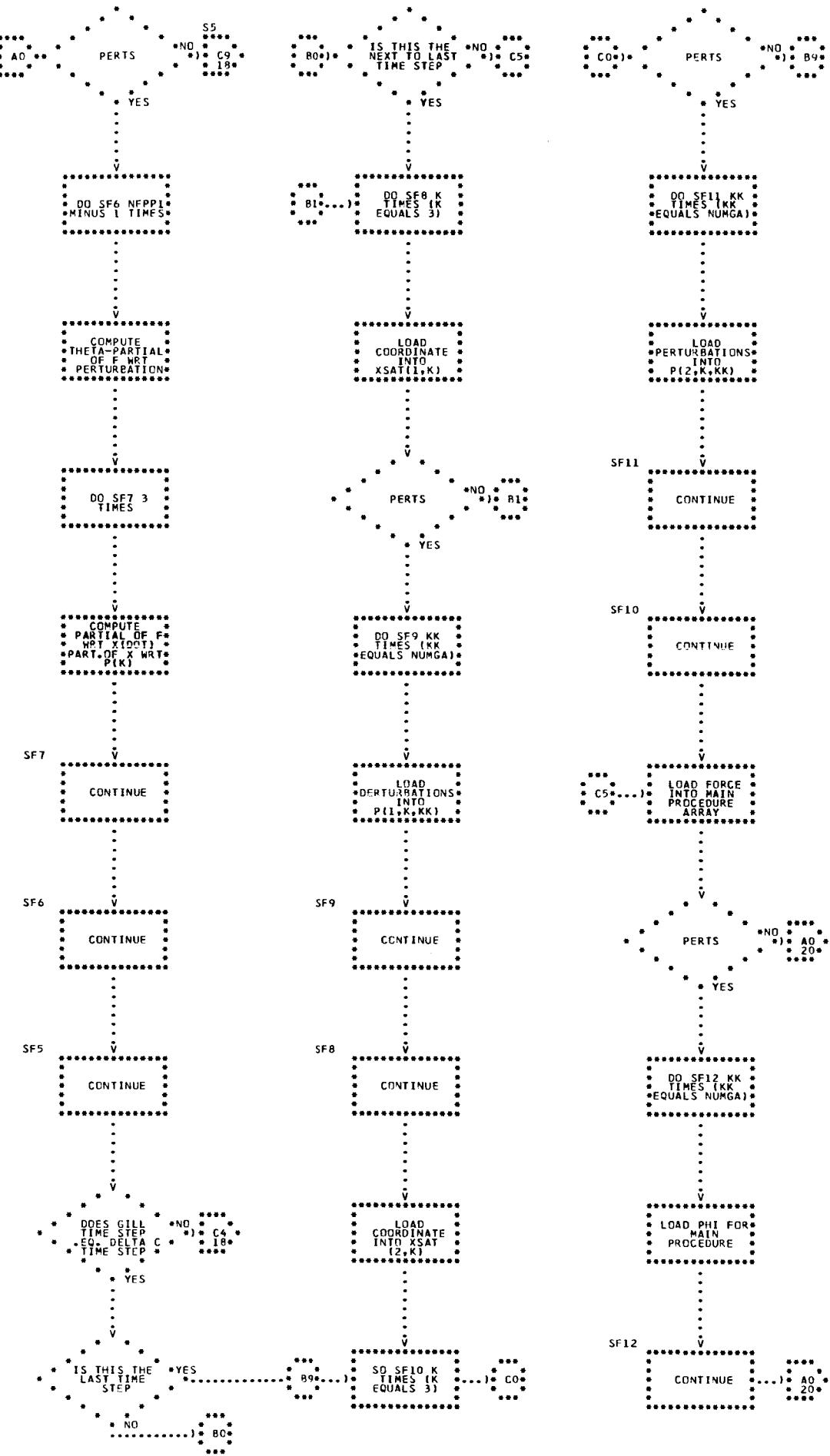


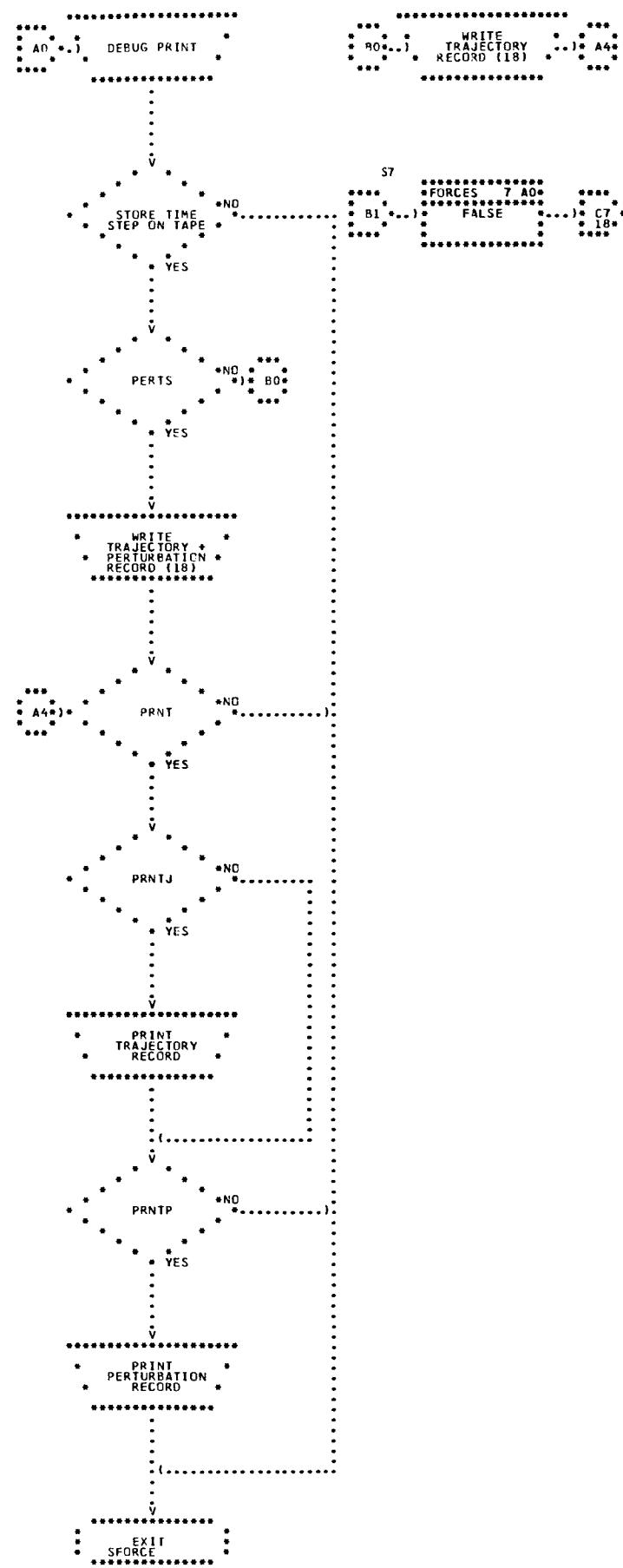


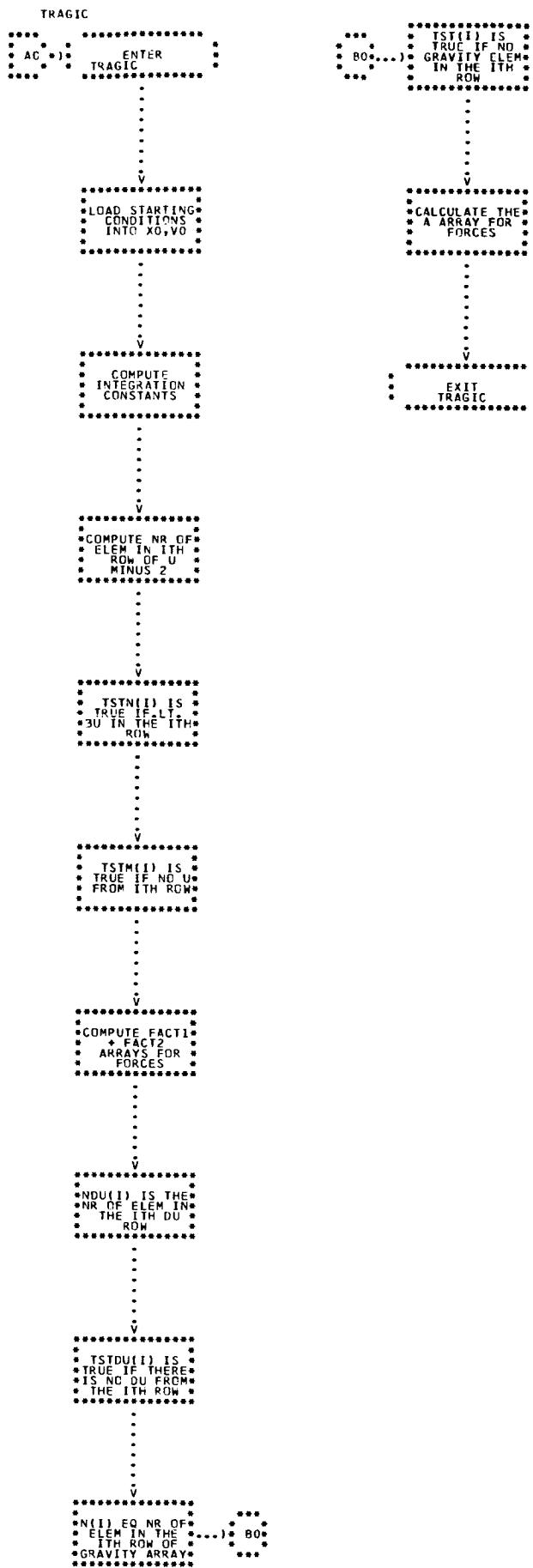


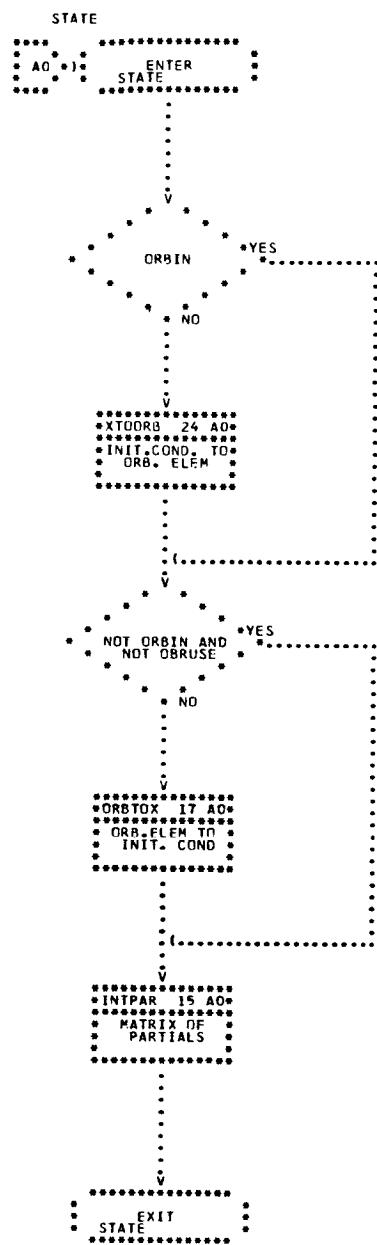


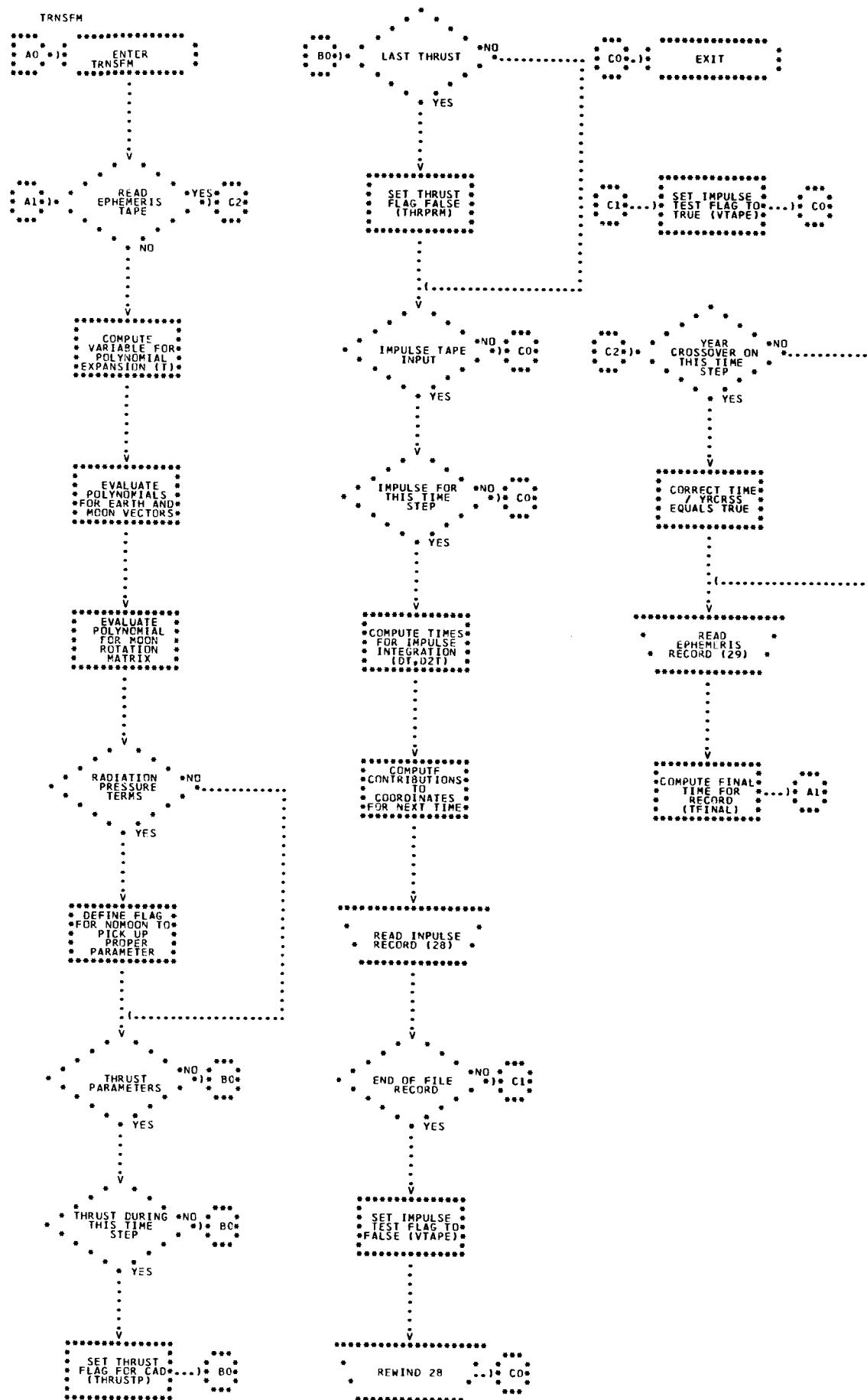


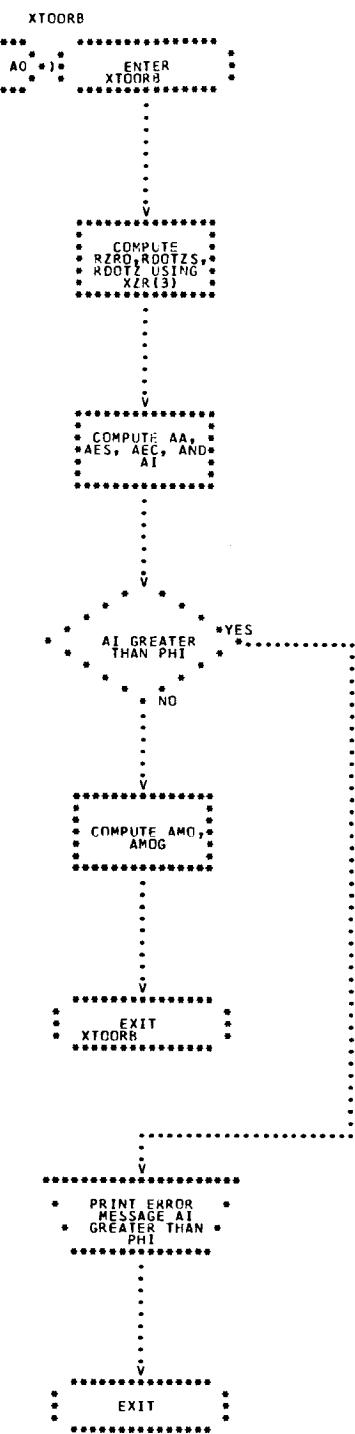












PART 5
NORMAL EQUATIONS PROGRAM

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SECTION I
INTRODUCTION

INTRODUCTION

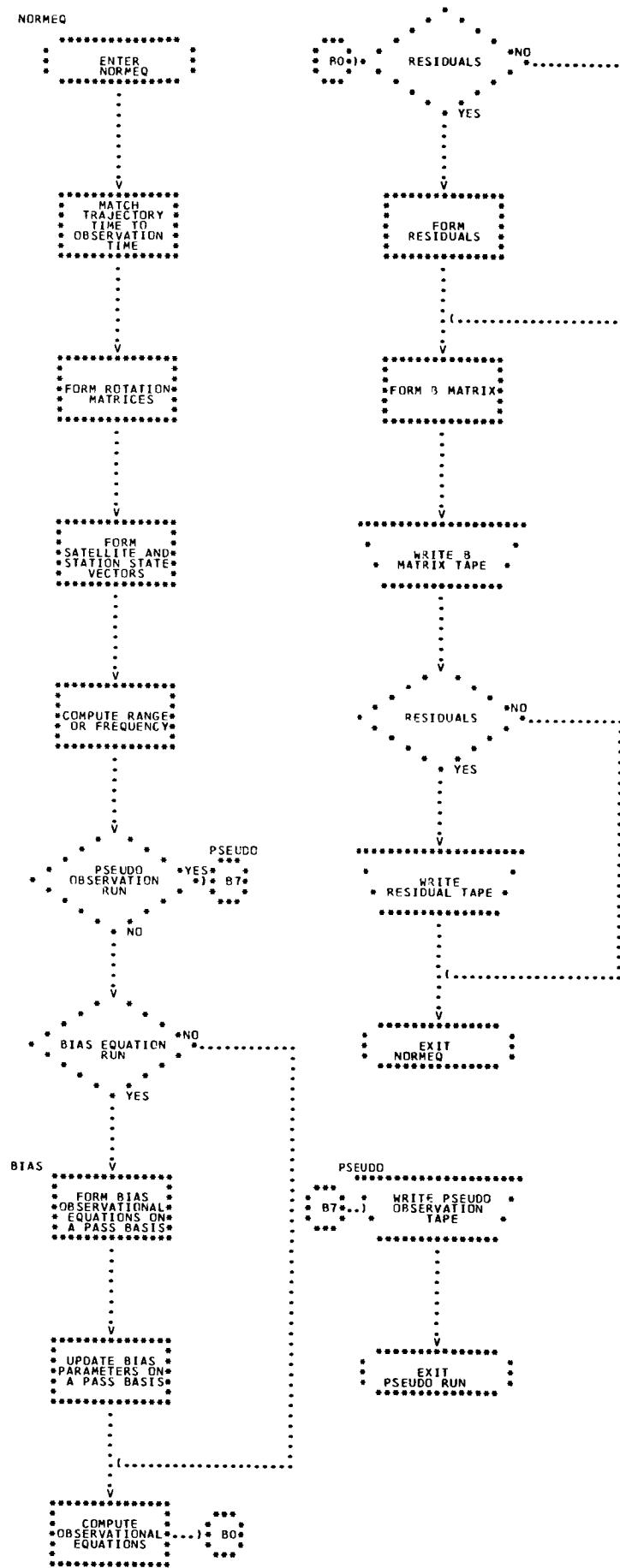
Using the calculated trajectory and perturbations, together with the filtered observational data, a matrix of observational equations is formed. Parameters occurring in these equations are the corrections to the lunar field harmonics, the initial conditions of the trajectory, the radiation pressure forces, the control thrust forces, the positions of the observing stations, the Earth-Moon distance, the speed of light, the errors in observing instruments and the model of atmospheric refraction correction.

A group of observations obtained from a specific sending and receiving station over a continuous period of time is termed a pass of observations. Of the parameters listed above, the four observing instruments and refraction correction parameters are capable of correction only within a single pass. Thus, for each pass of data, a solution (termed the bias solution) is performed which best-fits these four and up-dates the computed frequency accordingly. All other parameters may appear in the overall least-squares fit using data from all passes.

Having formed the observational equations, the normal equations for the arc are formed cumulatively, observation by observation. The resulting matrix and its associated right - hand side, termed a B-matrix, is stored on tape.

In addition to the usual processing of observed data, NOR MEQ can if required generate a "psuedo-observation" tape, which contains computed values in the format appropriate to observations.

SECTION II
SYSTEM FLOW CHART



SECTION III
USER INFORMATION

INPUT CARDS

1) Card type 0, Format (15L1)

<u>MN</u>	<u># of WORDS</u>	<u>C.C</u>	<u>FORMAT</u>	<u>CONTENT</u>
PRNT1	1	1	L1	Print B-matrix rows
PRNT2	1	2	L1	Print bias solution tape record
PRNT3	1	3	L1	Print range or frequency partials
PRNT4	1	4	L1	Print trajectory and perturbations
PRNT5	1	5	L1	Print earth-moon vector
PRNT6	1	6	L1	Print $(CD)^T$ matrix
PRNT7	1	7	L1	Print receiving station state vector
PRNT8	1	8	L1	Print bias B-matrix and formation
PRNT9	1	9	L1	Print sending station state vector
PRNT10	1	10	L1	Print time corrected station state vector
PRNT11	1	11	L1	Print clock corrected station state vector
PRNT12	1	12	L1	Print A-matrix rows

2) Card type 10, Format (I5, I6, 2X, 2A6, 6X, I6, 12X, D23.16)

ITP	1	1-5	I5	Card type
ISATNC	1	6-11	I6	Satellite number
BNAME	2	14-25	2A6	B-matrix name
IDENTC	1	32-37	I6	Run identification
ARCST	2	49-72	D23.16	Start time of arc

3) Card type 20, Format (I5, 2D23.16)

<u>MN</u>	<u># of WORDS</u>	<u>C. C.</u>	<u>FORMAT</u>	<u>CONTENT</u>
ITP	1	1-5	I5	Card type
C	2	6-28	D23.16	Speed of light
DELTC	2	29-51	D23.16	Light travel time for mean earth-moon distance

4) Card type 30, Format (I5, D23.16)

ITP	1	1-5	I5	Card type
OMEGA	2	6-28	D23.16	Acceptable zenith angle

5) Card type 40, Format (I5)

ITP	1	1-5	I5	Card type (card type 40 signals beginning of station coordinates)
-----	---	-----	----	---

* 6) Card type xxx, Format (I3, 3D23.16)

IVT(I)	1	1-3	I3	Station number (I=1,6)
VT(I,1)	2	4-26	D23.16	γ)
VT(I,2)	2	27-49	D23.16	ϕ) station spherical coordinates
VT(I,3)	2	50-72	D23.16	λ)

* These cards must be in sort by station number. There are up to 6 of these cards, 1 for each station.

7) Card type 999, Format (I3)

ITP	1	1-3	I3	Final card for station coordinates
-----	---	-----	----	------------------------------------

8) Card type 60, Format (I5, 20L1) Program options

<u>MN</u>	<u># of WORDS</u>	<u>C.C.</u>	<u>FORMAT</u>	<u>CONTENT</u>
ITP	1	1-5	I5	Card type
DD	1	6	L1	Doppler data
RD	1	7	L1	Range data
AD	1	8	L1	Angle data (not used)
SPI	1	9	L1	Station parameters
EMA	1	10	L1	Earth-moon parameter
SLP	1	11	L1	Speed of light parameter
TBP	1	12	L1	Time bias
RCP	1	13	L1	Refraction correction
BIAS	1	14	L1	Bias solution
RBS	1	15	L1	Range bias
POT	1	16	L1	Pseudo observation tape
ALP	1	17	L1	Arc iteration
PWD	1	18	L1	Scale height of atmosphere
PWG	1	19	L1	Fudge factor
PFB	1	20	L1	Frequency bias
PRR		21	L1	Residuals

9) Card type 70, Format (I5, D23.16)

ITP	1	1-5	I5	Card type
GAMMA	2	6-28	D23.16	Fudge factor
DCONST	2	29-51	D23.16	Scale height of atmosphere

10) Card type 99, Format (I5)

MN	# of WORDS	C.C.	FORMAT	CONTENT
ITP	1	1-5	I5	Card type (Last card of required input constants)

OPTIONAL INPUT

11) Card type 5999, Format (I5, D23.16)

ITP	1	1-5	I5	Card type
SPRAM(4)	2	6-28	D23.16	Earth-moon parameter

This card is required if the earth-moon parameter option is on.

12) Card type xxxxx, Format (I5)

NPOLY	1	1-5	I5	Order of polynomial for $(B)^T$ matrix
-------	---	-----	----	--

* 13) Card type 0, Format (D20.13, 3D15.8)

TIMBT(I)	2	1-20	D20.13	Time of Δt , Δq , Δp values
DELTS(I)	2	21-35	D15.8	Values of Δt for polynomial
P(I)	2	36-50	D15.8	Values of Δp for polynomial
Q(I)	2	51-65	D15.8	Values of Δq for polynomial

* NPOLY must be greater than 1 and not more than 5. NPOLY (NUMBER) of these cards must be in deck.

OPERATING INSTRUCTIONS

- 1) The system control cards required in the overall deck setup are:
\$JOB

\$SETUP	04
\$SETUP	06 (omit if residual option not on)
\$SETUP	14
\$SETUP	15 (omit if pseudo-observation option not on)
\$SETUP	16 (omit if pseudo-observation option is on)
\$EXECUTE	IBJOB
\$IBJOB	
\$DATA	

NORMEQ data cards

- 2) The tape set up is

<u>DCS Unit</u>	<u>Tape Function</u>
04	Trajectory input tape (Binary)
05	Scratch tape or disk file (Binary)
06	Residual output tape (Binary)
14	Filtered observation input tape (Binary)
15	Pseudo-observation output tape (Binary)
16	B-matrix output tape (Binary)

- 3) Output consists of the B-matrix tape, pseudo-observation tape, residual tape, print of the input data and any optional printing.

PROGRAM RESTRICTIONS

1. If a bias solution is desired and only the partials with respect to frequency /or range bias and/or partial with respect to τ are to be included in the bias equation, then the bias solution option must be on.
2. The start time of the arc (ARCST) must be equal to or greater than the start time of the trajectory tape.
3. When the residual option is on, NORMEQ cannot handle more than 300 observations per pass.

ERROR MESSAGES

ROUTINE 1 - MAINZ

- 1 Trajectory header is not 100 record
- 2 Observation header is not 300 record
- 3 Observation weight record is not 305 record
- 4 Trajectory tape and NORMEQ identification does not match
- 5 Observation tape and NORMEQ satellite number does not match
- 6 Data class and run request do not match
- 7 Trajectory parameter and label record is not 110 record
- 8 The number of gravities on the trajectory tape is a negative number
- 9 Ephemeris data is not 130 record
- 10 Bias tape record is not a 400 or 410 record
- 12 Trajectory data is not 140 record
- 13 Observation tape record is not 320, - 310 or 330 record

ROUTINE 2 - ODATA

- 1 NPOLY is greater than 5 or less than 1

ROUTINE 3 - TREAD

- 1 Trajectory tape does not have correct record types

ROUTINE 4 - EREAD

- 1 Scratch Ephemeris tape does not have correct record types

ROUTINE 5 - RANGE

- 1 Parameters not indicated for bias solution

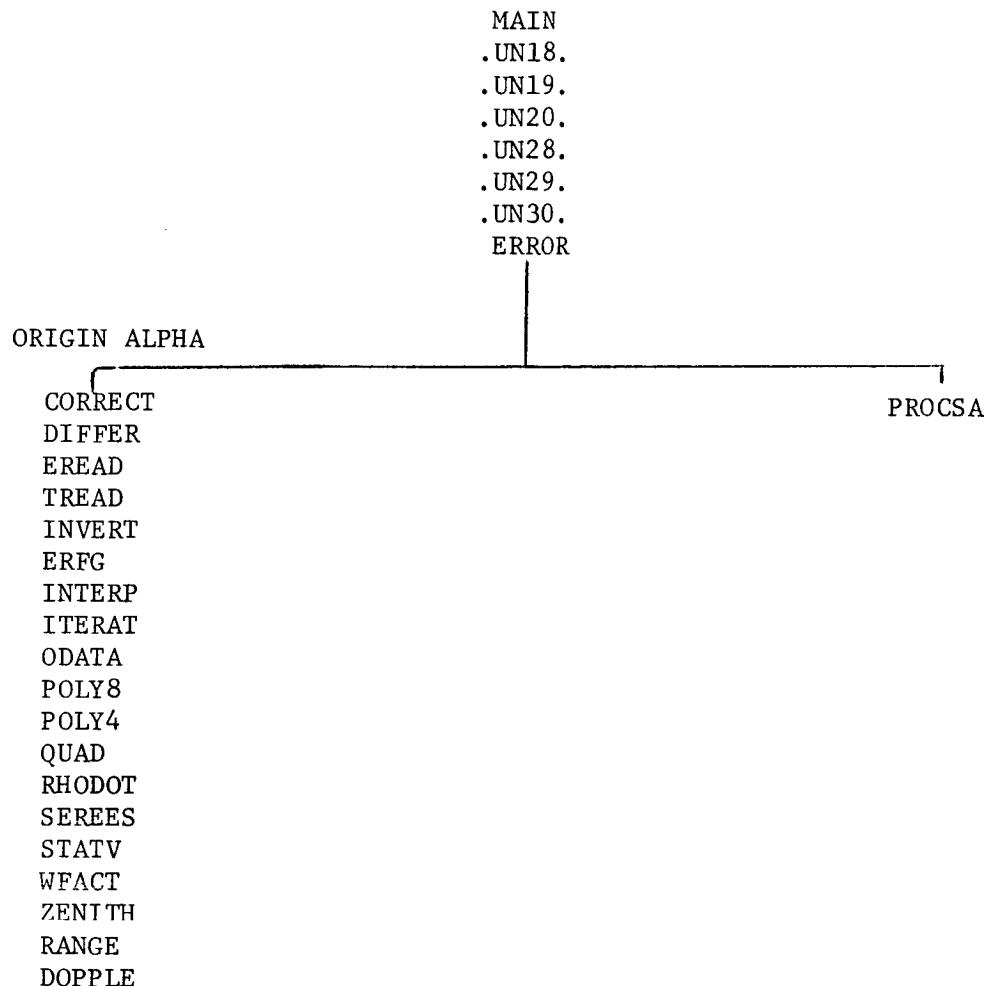
ROUTINE 6 - DOPPLE

1 Parameters not indicated for bias solution

ROUTINE 7 - PROCSA

1 Ephemeris tape out of sort

PROGRAM DECK ARRANGEMENT



FILE BLOCK PROGRAM OPTIONS

- 1) Tape 18:
 Filename is "UNIT18"
 Mode is "BIN"
 Unit assignment is "A(1)"

- 2) Tape 19:
 Filename is "UNIT19"
 Mode is "BIN"
 Unit assignment is "A(2)"

- 3) Tape 20:
 Filename is "UNIT20"
 Mode is "BIN"
 Unit assignment is "A(3)"

- 4) Tape 28:
 Filename is "UNIT28"
 Mode is "BIN"
 Unit assignment is "B(1)"

- 5) Tape 29:
 Filename is "UNIT29"
 Mode is "BIN"
 Unit assignment is "B(2)"

- 6) Tape 30:
 Filename is "UNIT30"
 Mode is "BIN"
 Unit assignment is "B(3)"

TAPE FORMATS

NORMEQ uses six tapes, identified in the codes as 18, 19, 20, 28, 29, 30, all binary. The function of each tape is as follows:

Tape 18

Input tape to NORMEQ, containing ephemeris, trajectory and perturbation data.

Tape 19

Scratch tape, holds rows of the A-matrix.

Tape 20

Output tape, residuals.

Tape 28

Input tape to NORMEQ, containing observation data.

Tape 29

Scratch tape, when bias solution option is on, contains state vectors and all other information pertaining to the bias solution on an observation pass basis.

Output tape, pseudo observation run.

Tape 30

Scratch tape, contains ephem data.

Output tape, contains B-matrix rows (input to SOLVE)

A-MATRIX TAPE FORMAT

Record type 210 A-matrix records

 220 End of file record

	<u># OF WORDS</u>	<u>MN</u>	<u>FORMAT</u>	<u>CONTENTS</u>
210	1	ITP	INTEGER	Record type
	2*1	FRHS	DOUBLE	Right hand side
	2*NFINAL	GAP	DOUBLE	Array of parameters of frequency or range with respect to gravity, arc and special parameters.
220	1	ITP	INTEGER	Record type (repeat of last 210 record)

BIAS SOLUTION TAPE FORMAT

	Record Type	400	Bias records
		410	End of file record

RECORD TYPE	#OF WORDS	MN	FORMAT	CONTENTS
400	1	ITYPET	INTEGER	Record type
	1	IOC	INTEGER	Class of data
	1	NUMBER	INTEGER	Receiving station number
	1	ISTATN	INTEGER	Sending station number
	2x1	TOBS	DOUBLE	Time of observation
	2x1	FX	DOUBLE	Observed frequency or range
	2x1	WGT	DOUBLE	Weight of observation
	2x1	FSEND	DOUBLE	Sending station frequency or range
	2x1	DCONST	DOUBLE	Scale height of atmosphere
	2x1	GAMMA	DOUBLE	Fudge factor
	2x3x4	XE	DOUBLE	Earth-moon vector XE(3,4)
	2x3x4	SSR	DOUBLE	Time corrected satellite 'state' vector SSR(3,4)
	2x3x4	SSS	DOUBLE	Time corrected sending station 'state' vector SSS (3,4)
	2x3x4	XJ	DOUBLE	Receiving station 'state' vector XK (3,4)
	2x3x2x3	PRAM1	DOUBLE	Receiving station partials and derivatives PRAM1 (3,2,3).

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENTS
	2x3x2NUMGA	PAAT	DOUBLE	Array of perturbations and derivatives PAAT(3,2,NUMGA).
	1	CONSNS	REAL	Sending station index of refractivity
	1	CONSNR	REAL	Receiving station index of refractivity
	2x3x4	XJE	DOUBLE	Receiving station-earth vector
	2x3x4	XJEL	DOUBLE	Sending station-earth vector
410	1	ITYPET	INTEGER	Record type
				Repeat last 400 record.
				For range data ISTATN and PRAM2 are not used and are dummy filled

FILTERED OBSERVATION TAPE FORMAT

RECORD TYPES

300	Tape header record
305	Weighting matrices
310	Pass header record
320	Data record
-320	Pass trailer record
330	End of file record

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENTS
300	1	ITYPE	INTEGER	Record type
	1	IDENTT	INTEGER	Tape identification number
	1	ISATNO	INTEGER	Satellite number
	1	ISYR	INTEGER	Start year for tape
	1x2	ARCSEC	DOUBLE	Start time for tape, in seconds from beginning of year
	1	ICLASS	INTEGER	Tape data class, "0" for doppler data, "3" for range data
305	1	ITYPE	INTEGER	Record type
	(3x10)x2	S	DOUBLE	Weighting matrix S
	(3x10)x2	T	DOUBLE	Weighting matrix T

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENTS
310	1	ITYPE	INTEGER	Record type
	1	IOPS	INTEGER	Number of observations in the pass
	1x2	STIME	DOUBLE	Start time of pass, in seconds from beginning of the year
	1x2	FTIME	DOUBLE	Final time of pass
	1	ISTATN	INTEGER	Receiving station number for pass
320	1	ITYPE	INTEGER	Record type
	1	NUMBER	INTEGER	Sending station number
	1	IDOP	INTEGER	Data class: "1" for doppler data, sending station equals receiving station; "2" for doppler data, sending station not equal to receiving station; "3" for range data.
	1	ICOND	INTEGER	Doppler data condition code, "0" for good data
	1x2	TIME	DOUBLE	Time of observation, in seconds from beginning of year
	1x2	TAU RBIAS	DOUBLE	TAU, for doppler data tapes is the elapsed time of doppler count, in seconds RBIAS, for range data tapes is the range bias
	1x2	FI RANGE	DOUBLE	FI, for doppler data tapes is the doppler observation RANGE, for range data tapes, is the range observation
	1x2	FREC	DOUBLE	Receiving station frequency

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENTS
	1x2	FSEND	DOUBLE	Receiving station frequency
	1x2	SIGF	DOUBLE	Partial weighting factor
	1	CONNR	REAL	Index of refractivity of receiving station
	1	CONNS	REAL	Index of refractivity of sending station
-320	1	ITYPE	INTEGER	Record type
	17	IDUM	INTEGER	Padding to fill record to same length as 320 records
330	1	ITYPE	INTEGER	Record type
	6	IDUM	INTEGER	Padding to fill record to same length as 310 record

PSEUDO-OBSERVATION TAPE

The pseudo-tape format is identical to the filtered observation tape format. The content of the 320 type record varies in that the observed range or frequency is replaced with the computed range or frequency.

RESIDUAL TAPE FORMAT

RECORD TYPE

700 Header
 710 Residual data
 710 End of file record

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENT
700	1	ITPE	INTEGER	Record type
	1	ISATNO	INTEGER	Satellite number
	2	BNAME	ALPHA	B-matrix name
	1	IBIAS	INTEGER	=0, no bias residuals =1, bias residuals
710	1	ITPE	INTEGER	Record type
	1	IOBS	INTEGER	Number of observations for this pass
	2x1	VI	DOUBLE	Signal to noise ration for this pass
	2x1	TOB1	DOUBLE	Time of first observation for this pass
	2xIOBS	RES	DOUBLE	Residuals
-710	1	ITPE	INTEGER	Record type (Repeat of Last 710 Record)

When bias residuals are present i.e. IBIAS=1, the bias residual record preceeds the normal residual record. Hence, for each pass, there will appear on the residual tape 2 records (bias and normal) corresponding to that pass.

TRAJECTORY AND PERTURBATION TAPE

RECORD TYPES

100	Trajectory tape header
110	Parameter and label record
120	Ephemeris header
130	Ephemeris records
140	Trajectory and perturbation records
150	Trajectory end of file record

FORMAT

RECORD TYPE	# OF WORDS	MN	FORMAT	CONTENT
100	1	ITYPET	INTEGER	Record type
	1	IDENTT	INTEGER	Identification number for arc
	1	ISATNO	INTEGER	Satellite number
	1	NUMGA	INTEGER	Number of partials calculated by INTEGRATION
	1	NUMGRV	INTEGER	Number of gravity partials calculated by INTEGRATION
	1	ISYR	INTEGER	Start year of ARC
	2	ARCSEC	DOUBLE	Start time of arc (seconds from beginning of year)
	2	ARCEND	DOUBLE	Time of last record (seconds from beginning of current year)
	2	DURA	DOUBLE	Duration of arc
	2	DELTAT	DOUBLE	Interval of storage

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENT
110	1	ITYPET	INTEGER	Record type
	NUMGAx2	PARAMS	DOUBLE	Initial parameter values for variables in integra- tion
	NUMGA	LABELS	INTEGER	Labels for parameters used in integration
120	1	ITYPET	INTEGER	Record type
	1	IDAY1	INTEGER	First day on tape (days from year start)
	1	IDAYS	INTEGER	Number of days of data equal number of Ephemeris records
	2	YRSECS	DOUBLE	Number of seconds in start year
	2	H1	DOUBLE	H for start year
	2	H2	DOUBLE	H for second year
130	1	ITYPET	INTEGER	Record type
	2	TZERO	DOUBLE	Base time for interpolation
	3x9x2	PXE	DOUBLE	INTERPOLATION Polynominal coefficients for earth- moon vector PXE(I,J)=I,3 J=1,9
	3x5x2	PCDTR	DOUBLE	Interpolation polynominal coefficients for Δh PBTR(I) I=1,5
	3x3x5x2	PECCTR	DOUBLE	PECCTR (I,II,J) I=1,3 II=1,3 J=1,5

RECORD TYPE	# of WORDS	MN	FORMAT	CONTENT
140	1	ITYPET	INTEGER	Record type
	2	TIMET	DOUBLE	Time of (position, acceleration and perturbations) seconds from beginning of year
	3x2	XSAT	DOUBLE	Position of satellite at TIMET (KM)
	3x2	ASAT	DOUBLE	Acceleration of satellite at TIMET(KM)
	3xNUMGAx2	P	DOUBLE	Array of perturbations
150	1	ITYPET	INTEGER	Record type
	2	TIMET	DOUBLE	Time of last trajectory and perturbation set
	3x2	XSAT	DOUBLE	Last position
	3x2	ASAT	DOUBLE	Last acceleration
	3xNUMGAx2	P	DOUBLE	Last array of perturbations

CARDS COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENTS
POLYTS	2x5	DOUBLE	Coefficients for Δt
POLYP	2x5	DOUBLE	Coefficients for p
POLYQ	2x5	DOUBLE	Coefficients for q
NPOLY	1	INTEGER	Order of polynomial fit for B^T -matrix

CDATA COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENT
OMEGA	2x1	DOUBLE	Acceptable zenith angle
C	2x1	DOUBLE	Speed of light
DELTC	2x1	DOUBLE	Light travel time for mean earth-moon distance
VT	2x3x6	DOUBLE	Cylindrical station coordinates ($\gamma z \lambda$)
CVT	2x3x6	DOUBLE	Cartesian station coordinates (x,y,z)
ARCST	2x1	DOUBLE	Start time of arc
SJ	2x3x10	DOUBLE	Weighting table
TJ	2x3x10	DOUBLE	Weighting table
PJ	2x3x10	DOUBLE	Weighting table
SPRAM	2x21	DOUBLE	Special partials parameters
IVT	6	INTEGER	Station numbers
ISATNC	1	INTEGER	Satellite number for run
NLV	1	INTEGER	Number of stations input for run
IDENTC	1	INTEGER	Identification number for trajectory tape
NFINAL	1	INTEGER	Number of partials in NORMEQ row of A-matrix
JOBS	1	INTEGER	Total number of accepted observations
NTOTAL	1	INTEGER	Temporary cell

NAME	# of WORDS	FORMAT	CONTENTS
LBP	1	INTEGER	Temporary cell
BNAME	2	ALPHA	B-matrix name
J1	1	LOGICAL	Cell used in processing A-matrix tape
SJA	1	LOGICAL	Cell used in processing A-matrix tape
WORD	20	LOGICAL	Program options
WORD(1)-DD	1	LOGICAL	Doppler data
WORD(2)-RD	1	LOGICAL	Range data
WORD(3)-AD	1	LOGICAL	Not used
WORD(4)-SPI	1	LOGICAL	Station partials
WORD(5)-EMA	1	LOGICAL	Earth-moon multiplier
WORD(6)-SLP	1	LOGICAL	Speed of light
WORD(7)-TBP	1	LOGICAL	Time bias (TAU)
WORD(8)-RCP	1	LOGICAL	Refraction correction
WORD(9)-BIAS	1	LOGICAL	Bias solution
WORD(10)-RBS	1	LOGICAL	Range bias
WORD(11)-POT	1	LOGICAL	Pseudo-observation
WORD(12)-AIP	1	LOGICAL	Arc iteration
WORD(13)-PWD	1	LOGICAL	Scale height of atmosphere
WORD(14)-PWG	1	LOGICAL	Fudge factor
WORD(15)-PFB	1	LOGICAL	Frequency bias
WORD(16)-RESO	1	LOGICAL	Residuals
WORD(17) TO WORD(20)			NOT USED

DCLASS COMMON DEFINITIONS

<u>NAME</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENT</u>
XJ1	2x3x4	DOUBLE	Sending station 'state' vector
XJE1	2x3x4	DOUBLE	Sending station-earth vector
SSR	2x3x4	DOUBLE	Satellite position at transmission time
SSS	2x3x4	DOUBLE	Time corrected sending station vector
RHOBR	2x3x4	DOUBLE	Difference of receiving station 'state' vector and satellite position at transmission time
RHOR	2x4	DOUBLE	Absolute value of RHOBR
RHOBS	2x3x4	DOUBLE	Difference of sending station 'state' vector and satellite position at transmission time.
RHOS	2x4	DOUBLE	Absolute value of RHOBS
GAP	2x100	DOUBLE	Array for NORMEQ partials
SMRHS	2x4	DOUBLE	Right hand side for bias B-matrix
SMBX	2x10	DOUBLE	Bias B-matrix (lower left side)
SFLIP	2x4x4	DOUBLE	Bias B-matrix
SOLUT	2x4	DOUBLE	Bias B-matrix solutions
PRAM1	2x3x2x2	DOUBLE	Receiving station partials and derivatives
PRAM2	2x3x2x2	DOUBLE	Sending station partials and derivatives
DT1	2x1	DOUBLE	Temporary cells used in data class routines

NAME	# of WORDS	FORMAT	CONTENT
DT2	2x1	DOUBLE	Temporary cells used in data class routines
DT3	2x1	DOUBLE	Temporary cells used in data class routines
EMP2	2x1	DOUBLE	Temporary cells used in data class routines

HEAD COMMON DEFINITIONS

<u>NAME</u>	<u># of WORDS</u>	<u>FORMAT</u>	<u>CONTENTS</u>
ARCSEC	2x1	DOUBLE	Start time of arc (seconds from beginning of year.)
ARCEND	2x1	DOUBLE	TIME OF LAST RECORD (seconds from beginning of current year) TRAJECTORY TAPE
DURA	2x1	DOUBLE	Duration of arc
DELTAT	2x1	DOUBLE	Interval of storage
YRSECS	2x1	DOUBLE	Number of seconds in start year
H1	2x1	DOUBLE	H for start year
H2	2x1	DOUBLE	H for current year
IDENTT	1	INTEGER	Identification number for arc
ISATNO	1	INTEGER	Satellite Number
NUMGA	1	INTEGER	Total number of perturbations
NUMGRV	1	INTEGER	Number of gravity partials
ISYR	1	INTEGER	Start year of arc
IDAY1	1	INTEGER	First day on tape (days from year start)
IDAYS	1	INTEGER	Number of days of data equals number of ephem records

INDATA COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENT
TIMET	2x8	DOUBLE	Eight time steps from trajectory tape
TZERO	2x1	DOUBLE	Time of ephemeris data
TIME	2x1	DOUBLE	Time of observation
S	2x1	DOUBLE	Variable input to interpolation routine
PXE	2x3x9	DOUBLE	Interpolation polynomial coefficients for earth-moon vector (XE).
PCDTR	2x3x3x5	DOUBLE	Interpolation polynomial coefficients for rotation matrix $[CD]^T$.
PBTR	2x5	DOUBLE	Interpolation polynomial coefficients for Δh .
F	2x8x3x2	DOUBLE	Interpolation coefficients for position and acceleration of satellite
PERT	2x8x3x75	DOUBLE	Interpolation coefficients for perturbations
PARAMS	2x100	DOUBLE	Parameter values for elements in B-matrix
LABELS	100	INTEGER	Labels for elements in B-matrix

MAIN COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENT
G	2x3x2x2	DOUBLE	Satellite 'state' vector and derivatives
PAAT	2x3x2x75	DOUBLE	Perturbations and derivatives
XE	2x3x4	DOUBLE	Earth-moon vector
CD	2x3x3	DOUBLE	$[CD]^T$ matrix
R	2x4	DOUBLE	p,q, Δh , Δt array
PROD	2x3x3	DOUBLE	$[CD]^T [B]^T$ matrix
XJ	2x3x4	DOUBLE	Receiving station 'state' vector
XJE	2x3x4	DOUBLE	Receiving station-earth vector
PBTR	2x5	DOUBLE	Coefficients for Δh .

OBS COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENT
TIME-TOBS	2x1	DOUBLE	Time of observation
TAU-RBIAS	2x1	DOUBLE	Elapsed time of doppler count/Range bias
FX	2x1	DOUBLE	Averaged doppler observation
SIGR-SIGF	2x1	DOUBLE	Weighting component for range or doppler data
FSEND	2x1	DOUBLE	Sending station frequency
IOBS	1	INTEGER	Number of observations in a pass
IDOP	1	INTEGER	Doppler data class indicator
ICOND	1	INTEGER	Doppler data condition code
IREC	1	INTEGER	A-matrix tape record counter
ICLASS	1	INTEGER	Data class indicator
NUMBER	1	INTEGER	Sending station number
ISTATN	1	INTEGER	Receiving station number
FREQ	2x1	DOUBLE	Receiving station frequency
RFC	2x4	DOUBLE	Refraction correction array
MOBS	1	INTEGER	Bias solution pass record counter
CONSNR	1	REAL	Receiving station index of refractivity
CONSNS	1	REAL	Sending station index of refractivity
STIME	2x1	DOUBLE	Start time of pass
FTIME	2x1	DOUBLE	Final time of pass

OPTION COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENT
PRNT1	1	LOGICAL	Print B-matrix rows and right-hand side; if residual option is on print number of observations accepted, variance, signal-to-noise ratio.
PRNT2	1	LOGICAL	Print bias solution tape record
PRNT3	1	LOGICAL	Print range or frequency partials and computed range or frequency.
PRNT4	1	LOGICAL	Print interpolated trajectory and perturbation array.
PRNT5	1	LOGICAL	Print earth-moon vector
PRNT6	1	LOGICAL	Print $(CD)^T$ and $(BCD)^T$
PRNT7	1	LOGICAL	Print receiving station 'state' vector
PRNT8	1	LOGICAL	Print bias B-matrix and solution
PRNT9	1	LOGICAL	Print sending station 'state' vector; if station parameter option is on, print station partials and derivatives
PRNT10	1	LOGICAL	Print time corrected 'state' vectors
PRNT11	1	LOGICAL	Print clock corrected 'state' vectors
PRNT12	1	LOGICAL	Print A-matrix rows and right-hand side

RESDUL COMMON DEFINITIONS

NAME	# of WORDS	FORMAT	CONTENT
VV1	2x1	DOUBLE	Bias signal to noise ration
VV2	2x1	DOUBLE	Temporary storage
RES	2x300	DOUBLE	Residuals for pass
V1	2x1	DOUBLE	Signal to noise ratio
IBIAS	1	INTEGER	Indicates bias or non-bias residuals
IMAX	1	INTEGER	Number of residuals for a pass

SECTION IV
SUBROUTINE WRITE-UPS

NAME	MAINZ
PURPOSE	Overall control program for NORMEQ
CALLS	<p>ODATA Read Run I. D. , print options, program options, constants and station coordinates from cards.</p> <p>TREAD Position and read Trajectory/Perturbation data from Trajectory/Perturbation tape (18).</p> <p>INTERP Form position, acceleration, velocity , 3rd der.</p> <p>ERead Position and read Ephemeris data from tape (30).</p> <p>POLY8 Form earth-moon vector using an eighth order polynomial fit.</p> <p>POLY4 Form (CD^T) matrix from fourth order polynomial fit.</p> <p>STATV Compute receiving station-earth vector and if the station partial option is on, calculate the receiving station partials.</p> <p>DOPPLE Calculate doppler frequency, bias solution B-matrix and rows of the A-matrix.</p> <p>RANGE Calculate range, bias solution B-matrix and rows of the A-matrix.</p> <p>PROCSA Sum the rows of the A-matrix; if processing of the observation tape is incomplete, write partial B-matrix to B-matrix tape; if processing of the observation tape is complete, write header, parameters, labels, B-matrix, and trailer to B-matrix tape (30).</p>

	INVERT	Invert bias B-matrix
	ERROR	Error routine
INPUT	Trajectory and perturbation tape (18). *+ Ephemeris data (30) Observation tape (28)	
OUTPUT	A-matrix tape (19) +B-matrix tape (30) ** Pseudo-observation tape/bias solution tape (29) Residual tape (20)	

* The ephemeris data is transferred onto this tape (30) from the trajectory and perturbation tape.

+ The ephemeris data appears first on this tape followed by partial B-matrix (if needed). At end of processing tape (30) is rewound, the full B-matrix is written onto this tape; tape (30) becomes the output B-matrix tape.

** If the pseudo-observation option is on, tape (29) becomes the output pseudo-observation tape. If the bias solution option is on, tape (29) is used as the bias solution tape.

NAME CORECT (ETA, XJE, RHOBR, RHOR, DCON2, DGAM2, X1, X2, X3,
X4, C, FSEND, W1, CONSNS)

PURPOSE Compute a) range correction;
b) range rate correction;
c) the partial of the range or frequency with
respect to δ (fudge factor);
d) the partial of the range or frequency with
respect to D (scale height of the atmosphere).

CALLED BY DOPPLE - doppler data class routine.
RANGE - range data class routine.

SUBROUTINE ERFG - Compute error function.
QUAD - Compute complimentary error function.

INPUT XJE station-earth vector.
RHOBR the difference of the time corrected station
'state' vector and the time corrected satellite
position.
RHOR absolute value of RHOBR vector.
DCON2 scale height of atmosphere.
DGAM2 δ (fudge factor)
CONSNS station index of refractivity.

X1 = TRUE, calculate range and range rate correction, and
if requested the partials of the range or frequency
with respect to δ and/or with respect to D.

X1 = FALSE, calculate range and range rate correction only.

X2 = TRUE, doppler data.

X2 = FALSE, range data.

X3 = TRUE, calculate the partial of the range or frequency with
respect to δ (fudge factor).

X4 = TRUE, calculate the partial of the range or frequency with
respect to D (scale height of the atmosphere).

C Speed of light

W1 Constant = (96*240)/221.

FSEND Sending station frequency.

OUTPUT ETA (1) Range correction.

ETA (2) Range rate correction

ETA(3)/ETA(4) Partial of range or frequency with respect
to δ (fudge factor) and/or partial of range
or frequency with respect to D (scale height
of the atmosphere).

NAME	DIFFER (V1, V2, VRES, NV)	
PURPOSE	Form difference of two vectors.	
CALLED BY	DOPPLE	Control program for doppler data class
	RANGE	Control program for range data class.
INPUT	V1	Vector (3, NV)
	V2	Vector (3, NV)
	NV	Number of functions
OUTPUT	VRES	Resultant vector (3, NV)

NAME	DOPPLE	(I 1, IOC, NUMGA, NUMGRV)
PURPOSE	Calculate doppler frequency, bias solution B-matrix and rows of the A-matrix.	
CALLED BY	MAIN	Overall control program for NORMEQ.
CALLS	ZENITH	Insure that the refraction correction model is an accurate representation of the physical phenomena.
	ITERAT	Perform light time correction to satellite and sending station 'state' vectors.
	SEREEES	If time bias option is on perform clock correction to satellite and station 'state' vectors.
	DIFFER	Calculate difference between satellite 'state' vector and station 'state' vector.
	RHODOT	Compute the radial distance, velocity, acceleration and 3rd derivative between satellite and station.
	STATV	Compute sending station-earth vector and if the station partial option is on calculate sending station partials.
	CORECT	Compute range correction, range rate correction, partial of frequency with respect to S and partial of frequency with respect to D.
	WFACT	Calculate weighting factor for A-matrix row and right-hand side.

	ERROR	Error routine.
INPUT	I 1	= 1, normal processing, calculate observational equation for doppler data class. Write row and right-side to A-matrix tape (29).
	I 1	= 2, bias solution processing, calculate the pass dependent quantities; clock, refraction correction, frequency bias. Form bias B-matrix. Write station and satellite 'state' vectors, perturbations, station partials and constants to bias solution tape (19).
	I 1	= 3, second pass of bias solution, perform clock correction to 'state' vectors; calculate observational equation for doppler data class. Write row and right-hand side to A-matrix tape (29).
	IOC	= 1, one way doppler data.
	IOC	= 2, two way coherent doppler data.
	IOC	= 3, two way non-coherent doppler data.
	NUMGA	Total number of gravity and arc parameters.
	NUMGRV	Number of gravity parameters.
OUTPUT		A-matrix tape (29); bias solution tape (19); pseudo-observation tape (29).

NAME	EREAD (TIME, IENT)	
PURPOSE	Read ephemeris data that corresponds to time of observation.	
CALLED BY	MAIN	Overall control program for NORMEQ
INPUT	TIME	Time of observation
	IENT	= True, initial entry to subroutine
	IENT	= False, subsequent entries to subroutine.
OUTPUT	TZERO	Time of ephemeris data
	PXE	Interpolation polynomial coefficients for earth-moon vector, PXE (3, 9)
	PCDTR	Interpolation polynomial coefficients for rotation matrix $(CD)^T$, PCDTR (3, 3, 5)
	PBTR	Interpolation polynomial coefficients for $\Delta h_{PBTR}(-5)$
NOTES	EREAD reads the ephemeris data from tape 30. All output goes into the INDATA common area.	

NAME ERFG (A, B)

PURPOSE Evaluate G (g) when $g < 2$

CALLED BY CORECT - refraction correction routine

INPUT A - Value of g

OUTPUT B - Evaluation of G (g)

NAME ERROR (NERR, INDT)

PURPOSE Print error message with subroutine and error number indicated.

CALLED BY MAIN - overall control program for NORMEQ.
 RANGE - range data class routine.
 DOPPLE - doppler data class routine.
 TREAD - trajectory tape read routine.
 EREAD - ephemeris tape read routine.
 PROCSA - A-matrix tape processing routine.

INPUT NERR - error indicator
 INDT - Subroutine indicator

NAME INTERP (F1, ICOMP, IINTER, DTIME, G1, S)

PURPOSE Form position, acceleration, velocity and third derivative of trajectories and perturbations.

CALLED BY MAIN, overall control program for NORMEQ

INPUT F1 Input table of trajectories and perturbations
 F1(8, 3, 77)
 ICOMP Number of components
 IINTER Number of functions
 DTIME Interval of storage
 S ($T_{\text{obs}} - 4^{\text{th}}$ time step)/ interval of storage

OUTPUT G1 Output table of interpolated trajectories and perturbations G1(3,2,77)

NAME INVERT (A,N)

PURPOSE Invert NXN matrix A

METHOD A Crout inversion without pivot search

CALLED BY ODATA - invert Δp , Δq , Δt matrix
 MAIN - invert bias B-matrix

INPUT A matrix to be inverted
 N order of matrix

OUTPUT A inverted matrix

NAME	ITERAT (ND, R1, R2, R3, AA, AB, DELTC, CA)	
PURPOSE	Perform time correction to satellite 'state' vector and sending station 'state' vector.	
CALLED BY	DOPPLE	Control program for doppler data class.
	RANGE	Control program for range data class.
INPUT	ND = 1,	Perform time correction to satellite 'state' vector.
	ND = 2,	Perform time correction to satellite and sending station 'state' vectors.
	R1	Satellite 'state' vector, R1 (3, 2, 2).
	R2	Receiving station 'state' vector, R2 (3, 4).
	R3	Sending station 'state' vector, R3 (3, 4).
	DELTC	Light travel time for mean earth-moon distance.
	CA	Speed of light.
OUTPUT	AA	Time corrected satellite 'state' vector, AA (3, 4).
	AB	Time corrected sending station 'state' vector, AB (3, 4).
NOTES	Time correction is done when the run does not include bias solution or on the first pass in a bias solution.	

NAME ODATA (DCONST, GAMMA)

PURPOSE Read run identification, print options, program options, constants, station coordinates and special parameters from cards.

CALLED BY MAIN - overall control program for NORMEQ.

CALLS INVERT - invert Δp , Δq , Δt matrix
 SOLVE - solve for Δp , Δq , Δt .
 ERROR - input cards not in right order or are missing.

OUTPUT DCONST - scale height of atmosphere.
 GAMMA - input to refraction correction.

NOTES ODATA changes station coordinates to cartesian system and to cylindrical system.

NAME POLY4 (TIME, TZERO, FA, ICOMP, IINTER, H)

PURPOSE Evaluate 4th degree polynomial coefficients using nested technique.

CALLED BY MAIN Overall control program for NORMEQ.

INPUT TIME Time of observation

 TZERO Time of ephemeris record.

 FA Array of polynomial coefficients.
 FA (ICOMP, IINTER, 5).

 ICOMP Number of components of polynomial.

 IINTER Number of sets (functions) of polynomial
 coefficients.

OUTPUT H Evaluated polynomial H (ICOMP, IINTER)

NOTES POLY4 is used:
 (a) to evaluate 3 sets of 4th degree polynomial
 coefficients, each having 3 components for
 the $(CD)^T$ matrix.

NAME POLY8 (TIME, TZERO, EA, PH)

PURPOSE Evaluate an eighth degree polynomial centered at noon of the current day.

CALLED BY MAIN Overall control program for NORMEQ.

INPUT TIME Time of observation.

 TZERO Time of ephemeris record.

 EA Array of polynomial coefficients EA (3,9)

OUTPUT PH Evaluated polynomial PH (3, 4)

NOTES POLY8 is used to evaluate the moon-earth state vector.

NAME PROCSA (J1,SJA)

PURPOSE Process A-matrix tape (19); if run is incomplete write partial B-matrix behind ephemeris data on tape (30); if run is complete write final B-matrix (with header, etc.) to tape 30.

CALLED BY MAIN - Overall control program for NORMEQ

INPUT J1=TRUE, SJA=TRUE: form B-matrix; write B-matrix to ephemeris tape following ephemeris data and set SJA=FALSE.

J1=FALSE, SJA=TRUE: form B-matrix; write final B-matrix to tape (30).

J1=TRUE, SJA=FALSE: read previously formed B-matrix into core from ephemeris tape; add to B-matrix and write newly formed B-matrix to ephemeris tape following ephemeris data.

J1=FALSE, SJA=FALSE: read previously formed B-matrix into core from ephemeris tape, add to B-matrix and write final B-matrix to tape (30).

NAME QUAD (VV, AV)

PURPOSE Evaluate G (g) when $G \geq 2$

CALLED BY CORECT - refraction correction routine

INPUT VV - Value of g

OUTPUT AV - Evaluation of G (g)

NAME	RANGE (I1, NUMGA, NUMGRV)	
PURPOSE	Calculate range, bias solution B-matrix and rows of the A-matrix.	
CALLED BY	MAIN	Overall control program for NORMEQ.
CALLS	ZENITH	Insure that the refraction correction model is an accurate representation of the physical phenomena.
	ITERAT	Perform light time correction to satellite and sending station 'state' vectors.
	SEREEES	Perform clock correction to satellite and station 'state' vectors.
	DIFFER	Calculate difference between satellite and station 'state' vectors.
	RHODOT	Compute the radial distance, velocity, acceleration and third derivative between satellite and station.
	STATV	Compute the sending station-earth vector and if the station partial option is on calculate sending station partials.
	CORECT	Compute the range correction, range rate correction, partial of range with respect to S and partial of range with respect to D.
	WFACT	Calculate weighting factor for A-matrix row and right-hand side.
	ERROR	Error routine.

INPUT	I 1	= 1, normal processing, calculate observational equation for range data class. Write row and right-hand side to A-matrix tape (29).
	I 1	= 2, bias solution processing, calculate the pass dependent quantities; clock bias, refraction correction bias and range bias. Form bias B-matrix. Write station and satellite 'state' vectors, perturbations, station partials and constants to bias solution tape (19).
	I 1	= 3, second pass of bias solution, if time bias option is on perform clock correction to satellite and station 'state' vectors. Calculate observational equation for range data class. Write row and right-hand side to A-matrix tape (29).
	NUMGA	Total number of gravity and arc parameters.
	NUMGRV	Number of gravity parameters.
OUTPUT		A-Matrix tape (29), bias solution tape (19); pseudo-observation tape (29).

NAME	RHODOT (RHOA, RHOB)
PURPOSE	Compute the radial distance, velocity, acceleration and third derivative between the satellite and station.
CALLED BY	DOPPLE - Doppler data class routine. RANGE - Range data class routine.
INPUT	RHOA - Difference between satellite state vector and station state vector. RHOA (3,4).
OUTPUT	RHOB - Radial distance, velocity, acceleration and 3rd derivative between the satellite and the station . RHOB(4).

NAME SEREES (QA, DT, QB)

PURPOSE Perform clock correction to the satellite and station state vectors.

CALLED BY DOPPLE - Doppler data class routine
RANGE - Range data class routine

INPUT QA - State vector (3, 4)
DT - Time Lag

OUTPUT QB - Clock corrected position, acceleration, velocity and 3rd derr. (at signal reflection time) of satellite and station state vectors.

NAME STATV (UU, LV, CD, PR, VE, CT, SPI, P)

PURPOSE Compute station vector with respect to earth and if the station parameter option is on calculate station partials.

CALLED BY MAIN - Overall control program for NORMEQ.
 DOPPLE - Doppler data class routine.
 RANGE - Range data class routine.

INPUT LV - Pointer to station coordinates in (VE) Array.
 CD - $(CD)^T$ Matrix CD (3, 3)
 PR - $(BCD)^T$ Matrix PR (3, 3)
 VE - Station cartesian coordinates VE (3, 6)
 CT - Station standard cylindrical coordinates CT (3, 6)
 SPI - True - compute station partials
 - False - bypass computation of station partials

OUTPUT UU Station vector with respect to earth UU (3, 4)
 P Station Partials, P (3, 2, 3)

NOTES When called in MAIN, STATV is used to compute the receiving station vector and station partials. When called by DOPPLE or RANGE, STATV is used to compute the sending station vector and station partials.

NAME	TREAD (TIME, TIMEA, DELTAA, ISPAN, IENT, S, F2, ILR, N).	
PURPOSE	Reads in appropriate trajectory and perturbation arrays.	
CALLED BY	MAIN - Overall control program for NORMEQ.	
INPUT	TIME	Time of observation.
	TIMEA	4th time step (on trajectory tape) from previous tape read; or , if initial positioning of tape, TIMEA will be equal to the initial time on the trajectory tape - 5* the time step interval (DELTAA).
	DELTAA	Time step interval.
	ISPAN	= 2, when run spans years. = 1, otherwise.
	IENT	= True, Initial entry to TREAD. = False, all subsequent entries.
	N	Total nr. of trajectory and perturbation functions.
OUTPUT	S	Variable for 8 point Legrangian.
	F2	Storage table F2 (I, J, K) I=1, 8, J=1, 3 K = 1, N.
	ILR	Set to 3-normal return . Set to 2-observation time occurs after final trajectory time. Set to 1-observation time occurs before initial trajectory time.
NOTES	TREAD uses tape 18.	

NAME WFACT(WGT)

PURPOSE Calculate weighting factor for A-matrix row and right-hand side.

CALLED BY DOPPLE - doppler data class routine.
 RANGE - range data class routine.

OUTPUT WGT - weight to be applied to A-matrix elements and right-hand side.

NOTES If the bias solution option is on, the weighting factor is applied to the bias A-matrix rows and right-hand side; it is not applied on the second bias pass.
 If the bias solution option is not on, the weighting factor is applied to the normal A-matrix rows and right-hand side.

NAME	ZENITH (ZX, ZXJE, ZXJ, ANGLE, IZ)
PURPOSE	To insure that the refraction correction model is an accurate representation of the physical phenomena.
CALLED BY	DOPPLE - Doppler data class routine. RANGE - Range data class routine.
INPUT	ZX - Satellite state vector. ZX (3, 2, 2) ZXJE - Sending or receiving station vector with respect to the earth. ZXJE (3, 4) ANGLE - Acceptable Zenith angle.
OUTPUT	IZ = 1, observation is not acceptable. IZ = 2, observation is acceptable. ZXJ - Sending or receiving station state vector. ZXJ (3, 4)

SECTION V
FLOW CHARTS

